

# Quality Evaluation of Potato Cultivars for Processing

WILBUR A. GOULD and SHARI PLIMPTON



Agricultural Experiment Stations of Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Ohio, South Dakota, and Wisconsin, and the U. S. Department of Agriculture cooperating.

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## FOREWORD

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# Quality Evaluation of Potato Cultivars for Processing

WILBUR A. GOULD and SHARI L. PLIMPTON<sup>1</sup>

## INTRODUCTION

Quality evaluation of new cultivars for the manufacture of potato products is essential to ensure that developmental efforts are fully realized. Many new cultivars may show great promise from the standpoint of high yield, disease and insect resistance, harvesting and handling efficiencies, or even storability; however, if unacceptable products are manufactured from these new cultivars, they are of little value to either the producer or the processor. Research workers in several states have evaluated new cultivars showing market potential and quality potato products. Increased efficiency in potato cultivar research has been achieved by coordination of individual research goals in regional research projects.

The key to the success of cooperative regional programs is the standardization of methodology for quality evaluation. In the North Central region, cooperative research has been enhanced by the Potato Research Laboratory, a facility developed by the Red River Valley Potato Growers Association, the Agricultural Experiment Stations of Minnesota and North Dakota, and the Agricultural Research Service, U. S. Dept. of Agriculture. Further, more standardization has been achieved in part by committees designated to discuss research goals and methods. Frequently, such meetings do not effectively communicate the precise methods involved or inadvertently fail to include potentially critical quality evaluation techniques. A manual detailing the methods used for quality evaluation and their procedures would fulfill a need for standardization of research techniques and provide a vehicle for producing results which may be understood and applied from state to state and from year to year.

The purpose of this bulletin is to furnish a complete program of potato cultivar evaluation for potato chip, french fry, and processed potato products. In the following sections, factors affecting the finished product quality will be discussed and methods for quantifying these factors will be reported. Among these factors considered to have a major influence on potato product quality are: potato size and shape, eye depth, peel, defects, flesh color, specific gravity, total and reducing sugars, peel loss during processing, chip color, chip defects, fry limpness, and storage characteristics.

## SAMPLING

Probably the greatest limiting factor in the successful evaluation of a new potato cultivar is the sample for

product evaluation. How many samples are needed and from where should they be obtained? The sample must be representative of the cultivar as it is grown in the region in question and must be selected at random. A poor, inadequate sample is worthless for evaluation of product quality if one is attempting to identify the true potential of the cultivar.

Cultivars to be evaluated should be planted in at least four test locations, representative of the production area in question, with a minimum of three replications. The method of planting, plot size, row length and spacing, seed piece spacing, and fertilizer rates should be controlled for each cultivar. A record should also be made of planting dates, vine killing dates if used, daily mean temperatures, rainfall, and harvesting dates. Ideally, the cultural practices for each trial should be similar to those used by commercial growers in the test area.

Upon harvest, a minimum of 10 lb of potatoes should be randomly selected from each replication, bagged, coded, and immediately transported to the processing research facility without wind and/or chilling effects. If storage evaluation is to be included in the study, three additional 10 lb samples of potatoes should be collected from each replication.

## RAW POTATO EVALUATION

Samples should be taken from each bag as received to evaluate for given quality attributes or characteristics. These include size and shape, specific gravity, peel, defects, pulp temperatures, flesh color, and sugars (reducing and non-reducing). Other quality aspects are best evaluated as the sample is being processed or after manufacture.

Size and shape are of particular importance in determining the suitability of a cultivar for potato processing. Large, round tubers are preferred by the chipper since their shape facilitates removal of the peel with minimal peel loss and the size provides chips which can be sized for the consumer. Chippers may use medium to small potatoes for individual serving-size packages for control of product weights. French fry manufacturers prefer large potatoes but require that they be oblong to long in shape to produce long fries with minimal losses.

### Size

Size may be established by measuring the immediate axis of the tuber and classifying the variety by the size distribution and/or by weight in ounces. Raw potato size classifications are given in Table 1.

Intermediate axis may be determined by passing the tubers through ring sizers designed at 4-1/4, 3-1/4, and

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**TABLE 1.—Raw Potato Size Classifications.**

Size Designation	Intermediate Axis (inches)		Weight in Ounces
	Minimum	Maximum	
Very Small		less than 1-7/8	up to 4
Small	1-7/8	2-1/2	up to 6
Medium	2-1/2	3-1/4	up to 10
Large	3-1/4	4-1/4	up to 16
Extra Large	4-1/4 or more		more than 16

2-1/2 inches, separating them into each size designation (large, medium, and small, respectively). A 10 lb sample from each replicate should be used and the size range should be reported as the percentage of tubers which fall into each size designation. For example, assume that a given 10 lb sample contains a total of 25 tubers. Within that sample, 3, 15, and 7 tubers were designated very small, small, and medium, respectively. Based on the equation:

Percent of Tubers in Size Classification =

$$\frac{\text{Number of Tubers in Size Classification}}{\text{Total Number of Tubers}} \times 100,$$

this sample contains 12% medium, 60% large, and 28% extra large tubers.

When reported in this manner, the size distribution is accurately recorded for the year in question. Accumulation of size data over a period of years permits a general size classification for the cultivar over a variety of conditions.

Another method of size determination is the total tuber count per 8 lb sample. Although this method is simpler, it provides only an average tuber size without any indication of the size distribution.

### Shape

Shape may vary considerably from season to season; however, cultivars are commonly classed as producing round, oblong, near flat, or long tubers. Shape designations are based on comparisons with standard cultivars such as Katahdin, a cultivar with elliptical to round tubers (Fig. 1). Kennebec and Russet Burbank are described as elliptical to long and long, respectively (Figs. 2 and 3).

### Eye Depth

Although this characteristic is somewhat variable, eye depth is an important processing factor which will

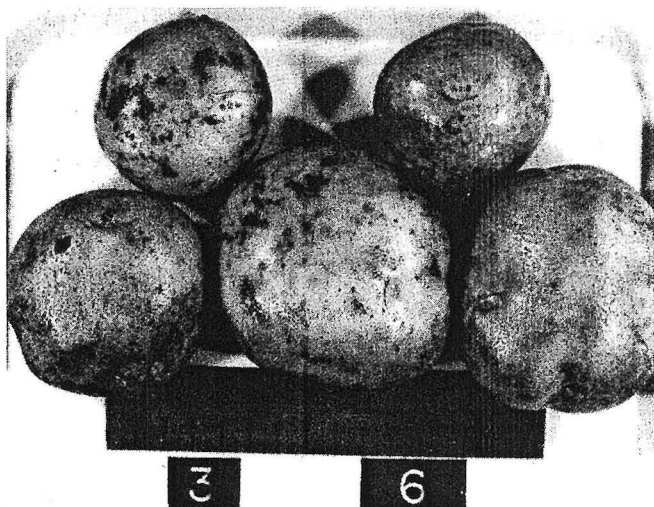


FIG. 1.—Katahdin.

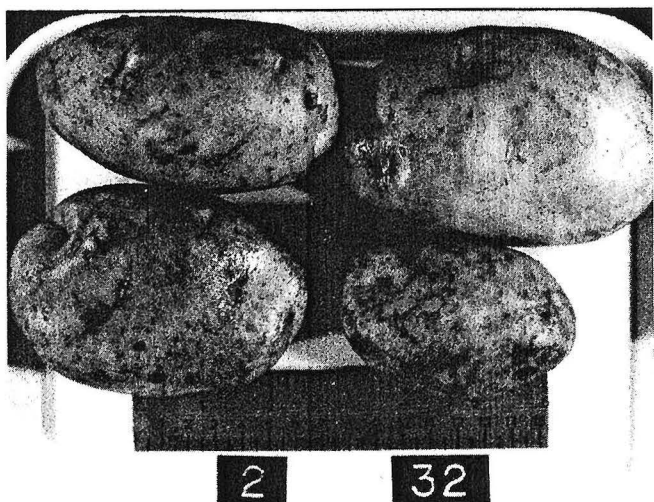


FIG. 2.—Kennebec.

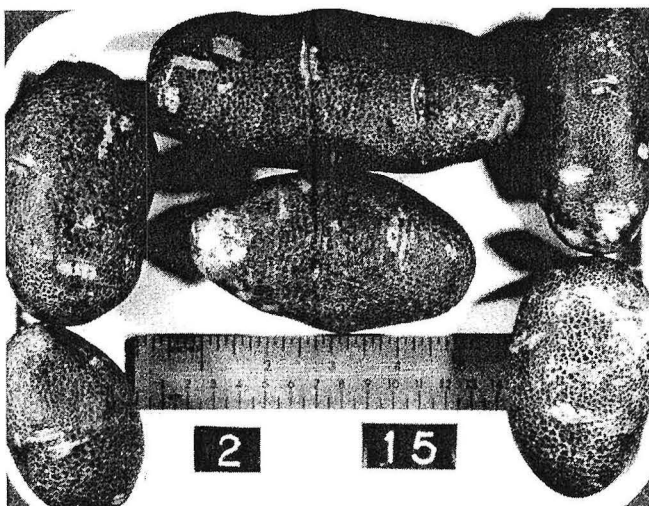


FIG. 3.—Russet Burbank.

influence peel and trim loss. Commonly, the eye depth is described as shallow or deep. Katahdin is known for its few shallow eyes (Fig. 1), while Russet Burbank typically has mid-deep eyes (Fig. 3). Raw potatoes may also be described in terms of peel color and thickness. Peel russetting is a cultivar trait and will vary depending on the season length and soil type, as will peel color.

### Specific Gravity

Specific gravity is a measure of the potato solids content. The specific gravity will influence process efficiency, oil adsorption in (chips and fries) the processed product, and product yield. There are high correlations between specific gravity, percent dry matter, and percent starch. Typical values showing the relationship of specific gravity to water content, dry matter, and starch content are given in Table 2. Starch is the major component of the tuber and comprises 65 of the 80% of the dry weight of the tuber. The single most important factor influencing the starch content is the cultivar. Secondary to cultivar is area of production and its related environmental factors.

To the chipper, the specific gravity has a direct relationship to the processing efficiency, time and temperature of frying, and yield or recovery of finished chips (Table 3). Higher chip yields are obtained with increasing specific gravity. Potatoes having higher specific gravity have also been shown to adsorb less cooking oil during the frying process. It stands to reason, since the frying operation is essentially a drying operation, that the more moisture or water in the potato or the less total solids to start with, the less solids in the end product and the more energy needed to remove the moisture.

Specific gravity will also influence the texture of potato products. The specific gravity is associated with dryness and mealiness for baked, boiled, and fried potatoes. For this reason, specific gravity is considered an excellent means for determining the final product quality.

Several methods are available for the measurement of specific gravity, although not all have the same degree of precision. Two significant points to remember when measuring the specific gravity of tubers are the tempera-

**TABLE 2.—Relationship of Specific Gravity, Water Content, Dry Matter, and Starch in Potatoes.**

Specific Gravity	Percent Water	Percent Dry Matter	Percent Starch
1.040	86.4	13.6	7.80
1.045	85.4	14.6	8.75
1.050	84.5	15.5	9.60
1.055	83.6	16.4	10.46
1.060	82.6	17.4	11.41
1.065	81.7	18.3	12.26
1.070	80.8	19.2	13.11
1.075	79.8	20.2	14.06
1.080	78.8	21.2	15.00
1.085	78.0	22.0	15.76
1.090	77.0	23.0	16.71
1.095	76.1	23.9	17.56
1.100	75.1	24.9	18.51
1.105	74.2	25.8	19.37
1.110	73.3	26.7	20.22
1.120	71.4	28.6	22.01
1.125	70.5	29.5	22.87
1.130	69.6	30.4	23.72
1.135	68.6	31.4	24.67
1.140	67.8	32.2	25.43

ture of the tuber or pulp temperature and the temperature of the water used in determining the specific gravity of the tubers. If these temperatures are not the same, the correction factors given in Table 4 should be used to adjust the reading. Tubers with hollow heart should be avoided for specific gravity determinations.

Reports from the Red River Valley Research Laboratory have shown that the specific gravity of individual tubers within a sample will vary 0.006 above or below the average specific gravity for that sample. These values may exceed  $\pm 0.006$  depending on different cultivars (Table 4). This means that in a sample with an average specific gravity of 1.080, some tubers may fall as low as 1.074 and others may be as high as 1.086.

### Specific Gravity Methods

#### *Weight in Air/Weight in Water Method*

One way to know the variation in a given cultivar is to determine the specific gravity of 60 to 100 individual

**TABLE 3.—Influence of Specific Gravity on Chip Yield and Chip Oil Content.\***

Specific Gravity	Yield of Chips In Percent	Oil Content of Chips In Percent	Yield of Chips Zero Oil Basis In Percent
1.060	28.44	47.04	14.87
1.065	29.22	45.71	15.76
1.070	30.00	44.38	16.66
1.075	30.78	43.05	17.56
1.080	31.56	41.72	18.45
1.085	32.33	40.39	19.35
1.090	33.11	39.06	20.25
1.095	33.89	37.73	21.14
1.100	34.67	37.40	22.04
1.105	35.45	35.07	22.94
1.110	36.23	33.74	23.83

\*Calculated using linear regression equations of Lulai and Orr (9).

**TABLE 4.—Correction Factors for Specific Gravity of Potatoes Corrected to Zero Base of 50° F Tuber Temperature and 50° F Water Temperature.**

Tuber Temperature	Water Temperature (Degrees Fahrenheit)									
	30°	40°	45°	50°	55°	60°	65°	70°	75°	80°
38°	-0.0021	-0.0020	-0.0018	-0.0018	-0.0020	-0.0023	-0.0029	-0.0038	-0.0047	-0.0056
40°	-0.0017	-0.0016	-0.0014	-0.0014	-0.0016	-0.0019	-0.0034	-0.0034	-0.0043	-0.0052
45°	-0.0009	-0.0008	-0.0006	-0.0006	-0.0008	-0.0011	-0.0017	-0.0026	-0.0035	-0.0044
50°	-0.0003	-0.0002	-0.0000	-0.0000	-0.0002	-0.0005	-0.0011	-0.0020	-0.0029	-0.0038
55°	+0.0001	+0.0002	+0.0004	+0.0002	-0.0001	-0.0001	-0.0007	-0.0016	-0.0025	-0.0034
60°	+0.0004	+0.0005	+0.0007	+0.0007	+0.0005	+0.0002	-0.0004	-0.0013	-0.0022	-0.0031
65°	+0.0005	+0.0006	+0.0008	+0.0008	+0.0006	+0.0003	-0.0003	-0.0012	-0.0021	-0.0030
70°	+0.0006	+0.0007	+0.0009	+0.0009	+0.0007	+0.0004	-0.0002	-0.0011	-0.0020	-0.0029
75°	+0.0007	+0.0008	+0.0010	+0.0010	+0.0008	+0.0005	-0.0001	-0.0010	-0.0019	-0.0028
80°	+0.0008	+0.0009	+0.0011	+0.0011	+0.0009	+0.0006	+0.0000	-0.0009	-0.0018	-0.0027
85°	+0.0009	+0.0010	+0.0012	+0.0012	+0.0010	+0.0007	+0.0001	-0.0008	-0.0017	-0.0026
90°	+0.0010	+0.0011	+0.0013	+0.0013	+0.0011	+0.0008	+0.0002	-0.0007	-0.0016	-0.0025
95°	+0.0011	+0.0012	+0.0014	+0.0014	+0.0012	+0.0009	+0.0003	-0.0006	-0.0015	-0.0024
100°	+0.0012	+0.0013	+0.0015	+0.0015	+0.0013	+0.0010	+0.0004	-0.0005	-0.0014	-0.0023

tubers. The specific gravity of each tuber may be determined by weighing each tuber in air and then in water and calculating the specific gravity by the equation:

$$\frac{\text{Weight in Air}}{\text{Weight in Air} - \text{Weight in Water}} = \text{Specific Gravity}$$

A scale, basket, and 2-3 gallon container are needed. The water and potatoes should be at the same temperature, 20° C (68° F). The potatoes should be washed to remove any soil and should be cut after determining the specific gravity to make certain that none of the tubers have hollow heart.

#### Brine Solution Method

Brine solutions can be used to separate "floaters" and "sinkers". Table 5 contains the percent sodium chlo-

**TABLE 5.—Specific Gravity, Percent Salt, Degree Salometer, and Ounces of Salt per Gallon Relationships.**

Specific Gravity	Percent NaCl	Salometer Reading	Ounces of Salt
1.040	5.8	21.9	8.5
1.045	6.5	24.4	9.33
1.050	7.1	26.9	10.51
1.055	7.8	29.4	11.70
1.060	8.5	31.9	12.88
1.065	9.1	34.4	14.06
1.070	9.8	36.9	15.24
1.075	10.4	39.3	16.42
1.080	11.1	41.8	17.60
1.085	11.8	44.3	18.79
1.090	12.4	46.8	19.97
1.095	13.1	49.3	21.15
1.100	13.7	51.8	22.33
1.105	14.4	54.3	23.51
1.110	15.1	56.8	24.70
1.115	15.7	59.3	25.88
1.120	16.4	61.7	27.06
1.125	17.0	64.2	28.24
1.130	17.7	66.7	29.42
1.135	18.3	69.2	30.61
1.140	19.0	71.7	31.79

ride, ounces of salt per gallon, and salometer reading for each specific gravity. Individual tubers are placed in a brine solution. If the tuber floats and is of less specific gravity, it should be tested in the next lower brine solution(s). Conversely, if it sinks, it should be tested in the next higher solution(s). Tubers which do not float or sink in 30 seconds are considered equal to the brine solution. The same precautions as mentioned for the Weight in Air/Weight in Water method should be applied.

These methods will not only provide the average specific gravity, but will allow the separation of tubers and yield the range in specific gravity for each cultivar.

#### PC/SFA Hydrometer Method

A simple method for determining the specific gravity of a cultivar is the Potato Chip/Snack Food Association<sup>2</sup> hydrometer method. The hydrometer method is faster than the weight in air/weight in water or brine solution methods, but only provides an average specific gravity for a sample of 8 lb of potatoes. Three independent 8-lb samples are needed to obtain an average value. The equipment required is:

- 30-gallon drum
- Scale to weigh in pounds
- Potato hydrometer (available at PC/SFA)
- Basket (available at PC/SFA)
- Steel Rod 10-1/2 inches x 1/2 inch (available at PC/SFA)

The hydrometer is calibrated by first placing the steel rod in the basket used for the 8 lb of potatoes. Next the basket containing the rod should be attached to the hydrometer bulb and lowered into the drum filled with water. The hydrometer should read 1.070; if not, the chart inside the hydrometer tube may be raised or lowered until the water level is at the 1.070 mark of the hydrometer.

<sup>2</sup>Potato Chip/Snack Food Assoc., Suite I, 1711 King St., Arlington, VA 22314.

Eight pounds of dry, clean potatoes are weighed into the basket. If necessary, a potato may be cut to obtain exactly 8 lb. Holding the potatoes and basket in one hand, attach the hydrometer and place the potatoes, basket, and hydrometer into the 30-gallon drum filled with clean water. When the hydrometer comes to rest, floating free of the bottom and sides of the drum, take the reading at the water level. Repeat the procedure for each of three 8-lb samples. The three readings should be averaged and reported as the specific gravity for each lot of potatoes.

### **Flesh Color and Defects**

The quality factors previously mentioned may be evaluated with non-destructive methods before processing. Flesh color and internal defects require cutting randomly selected tubers for proper evaluation. Flesh color is potentially an important characteristic since it will greatly affect final product appearance. Cultivars available presently in the United States, though, are almost exclusively white-fleshed. The likelihood of encountering a new cultivar with cream or yellow flesh may be in the offing as several breeding programs now have selections with yellow flesh. A few random tubers are all that are required for visual color determination since flesh color is a fairly unalterable attribute.

Tubers with physical defects or disease should be included in the evaluation since these will have an effect on processing yield. Knobbiness, greening, scalding, scabbing, and many fungal, bacterial, and viral diseases may be detected by external inspection. Such defects cause peeling loss, trimming loss, and/or variable color or color patterns in potato products.

Tubers which are infected or injured during harvesting and handling can go over a grading table unnoticed, but when peeled they become a very noticeable defect. Potatoes may also look normal going into storage but may come out with rot. Several tubers should be cut to determine the occurrence of any internal defects such as internal black spot, pressure bruises, hollow heart, cambium layer discoloration, necrosis, translucency, rot, and/or sugar spots. The PC/SFA's defect chart provides illustrations of common defects for ease of identification. All defects should be noted and recorded by type as well as internal color.

### **Peel and Trim Loss**

Peel and defect loss may be evaluated separately in two sequential unit operations designed to indicate the degree of peeling and trimming necessary in production.

### **Sugar Content**

Changes in the carbohydrate content and metabolism are primary influences affecting the final product quality of processed potatoes. The measurement of sucrose and reducing sugars will indicate the maturity, storability, and processability of the potatoes.

The carbohydrate metabolism of the potato may be summarized as follows. During tuber growth, sucrose is the dominant sugar, reaching levels as high as 9 mg

sucrose/g (fresh weight). Sucrose is converted to starch during growth and a sucrose rating (SR) of 2 (mg/g tuber) or lower may be reached by harvest. If stored, the SR may increase under stressful conditions such as poor ventilation and temperature fluctuations. Enzymatic degradation of sucrose results in the formation of reducing sugars. The SR may again be decreased if the stress is relieved prior to senescent sweetening. In the senescent sweetening stage, the increase in sucrose is rapid and irreversible. Upon harvest, the amount of sucrose should be low (less than 2.7 mg. of sucrose/g of tuber.) Further, if the glucose is above 0.25 mg/g of tuber, the potato slices will fry too dark for acceptable quality. French fries and dehydrated potatoes are somewhat less susceptible to browning than potato chips, but even these products will become excessively dark if the reducing sugar content is high. Contrary to previous beliefs, a study by Ewing *et al.* (2) demonstrated that exposure to cold temperatures for short times (*i.e.*, 2 days) did not result in darker chip color.

The YSI 27 analyzer, available from most laboratory equipment supply firms, has proven to be a rapid and precise method of determining the glucose and sucrose contents of potatoes. An enzymatic method, the YSI 27 analyzer gives an exact assessment of glucose and sucrose excluding other reducing components in the tuber.

### ***Glucose and Sucrose Determination Using the YSI Analyzer (YSI Method)***

#### **Equipment:**

1. YSI 27 Analyzer and manuals equipped with a 2365 Glucose Membrane, 2357 Buffer, and two 2361 (25  $\mu$ l) Syringpets
2. 100 ml graduated cylinder; 500 ml volumetric flask; 500 ml beaker
3. Dextrose standard (YSI 2355-200 ml/dl) purchased from the company or Fisher Scientific Co.
4. Buffer Diluent — 15 g  $\text{Na}_2\text{HPO}_4$  and 40 g  $\text{NaH}_2\text{PO}_4$  per liter reagent water
5. Invertase Enzyme — Sigma Chemical Co. 14504 recommended
6. Balance to weigh in 0.1 gram
7. Acme Juicerator or Blender

#### **Procedure:**

1. Perform the instrument and membrane checks outlined on the inside front cover of the instrument and in the manual.
2. Choose tubers and remove about 200 grams from the center. Do not use apical or basal end. Research has shown apex to be low and basal high, with the center to be the average and most reliable concentration of sugars.
3. Weigh approximately 100 to 200 g of washed and peeled potatoes.



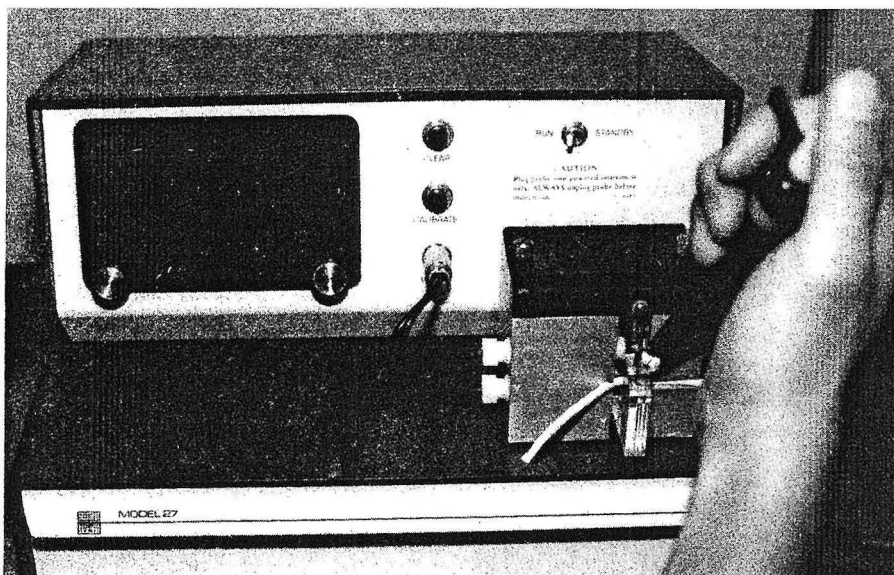


FIG. 4.—YSI 27 Analyzer.

4. Macerate or blend the potatoes blender or Acme juicerator and filter, collecting the juice in a beaker. Wash the juicerator three times with 100 ml portions of buffer diluent described in 4 under Equipment. Wait 2 to 3 minutes between rinsings.
5. Quantitatively transfer the combined juice and buffer into a 500 ml volumetric flask. Rinse the beaker with several small (10 ml) aliquots of buffer and add to the volumetric flask. Now dilute to the mark with buffer. Refrigerate for 1 hour at 5° C (41° F).
6. Take a 3 ml aliquot of sample from procedure 5 and add approximately 2 mg of invertase enzyme, stir gently until dissolved. Set this aside for 20 minutes.
7. Rinse the syringpet twice with sample prepared in procedure 5 and inject into previously standardized YSI 27 Analyzer (procedure 1).
8. Read result when "READ" light appears. The value displayed is the free glucose [Dextrose 1 (D1)].
9. Clear the instrument.
10. Rinse a DIFFERENT syringpet twice with sample prepared in procedure 6. Inject into the instrument.
11. Read result when READ light appears. The value displayed is the total of the free dextrose and that produced by sucrose hydrolysis [Dextrose 2 (D2)].
12. Clear the instrument.
13. Go to the next specimen, etc.

#### Calculations:

To calculate dextrose (mg/g):

$$D1^* \times \frac{\text{mg}}{100\text{ml}} \times \frac{500 \text{ ml}}{\text{g of Potatoes}} = \frac{\text{mg}}{\text{g}} \text{ Dextrose}$$

To calculate sucrose (mg/g):

$$(D2^{\dagger} - D1^*) \times \frac{(\text{mg})}{100 \text{ ml}} \times 1.9 \times \frac{500 \text{ ml}}{\text{g of Potatoes}} = \frac{\text{mg}}{\text{g}} \text{ Sucrose}$$

\*See procedure 8 above.

†See procedure 11 above.

#### **Glucose and Sucrose Determination by the YSI Analyzer (Sowokinos Method— an Alternative Method)**

##### **Equipment:**

1. YSI 27 Analyzer and Manuals (Fig. 4)
2. Blank Membranes
3. YSI Model 2717 dextrose membrane kit (± mutarotase)
4. Acme Juicerator with appropriate leak-free jar and top
5. Standards as purchased from the company
6. Balance to weigh in 0.1 gram
7. 600 ml beaker
8. 500 ml graduated cylinder
9. Knife for peeling and cutting tubers
10. Distilled water
11. Two clean syringpets

##### **Sample Juiceration:**

1. Wash, peel, and cut tubers lengthwise. Select pieces at random from one-half of each tuber to equal 200 g (0.441 lb)
2. Juicerate sample with the Acme juicerator, collect juice in a 600 ml beaker, and pass 100 ml cold distilled water three times through the juicerator, using the 100 ml graduated cylinder. Wait 2-3 minutes between washings.

3. Pour juice into a 500 ml graduated cylinder and take volume to 430 ml with distilled water. Pour juice back into the 600 ml beaker, mix with glass rod, cover with plastic wrap, and place in refrigerator at 5° C (41° F) for approximately 1 hour.

The juice is now ready for injection into the YSI model 27.

#### Procedure:

1. Run through the daily operational check, linearity check, and ferrocyanide test as indicated in the YSI operational manual.
2. Clear the instrument. When the ZERO/INJECT light appears, adjust to 0.
3. Rinse the syringpet twice with juice and then inject into sample chamber.
4. When READ light appears, the value displayed is the free glucose (*i.e.*, or dextrose).
5. Clear the instrument. When the ZERO/INJECT light appears, adjust to 0.
6. With a *different* syringpet (25  $\mu$ l), rinse the syringpet with invertase solution, fill the syringpet, and inject.
7. When the READ light appears, the value displayed is the invertase value.
8. With the first syringpet, rinse the juice again and inject another sample into the chamber.
9. Press the calibrate button and start following display until it stabilizes. Record this value = Final Reading. Approximate time is 3-4 minutes.
10. Clear the machine twice. Ready for repeating steps 2-9 with next sample.
11. The sucrose in mg per g of tuber (SR) may be calculated as follows:

Final Reading (Step 9) – Invertase (Step 7) – Free Glucose (Step 4) divided by 0.526\* x 0.0215† x 1.18‡ = SR = mg Sucrose/g Tuber.

\*Assuming each g of sucrose liberates 0.526 g glucose upon inversion.

†Value obtained after dividing represents mg sucrose/dl or 100 ml juice. Dilution factor represents 4.3 (*i.e.*, 430 total ml) divided by 200 total g = 0.0215.

‡Membrane efficiency factor (MEF) with dextrose-mutarotase membrane = 1.18 to agree with SR by anthrone procedure. MEF for dextrose + mutarotase membrane is 1.21.

### Sowokinos Testing for Sucrose-Rating (SR) by the van Handel Method

#### Equipment

1. Triple beam balance
2. Spectronic 20 (Bausch & Lomb)
3. Cuvettes (one-half inch test tubes) for spectronic 20
4. Marbles to cover cuvettes
5. Parafilm
6. Refrigerator or ice bath at 4° C

7. 500 ml graduated cylinder
8. 600 ml beaker
9. 5 ml pipettes
10. Rubber pipettor
11. Boiling water bath
12. Incubators (40° C; 104° F)

#### Reagents:

1. Sucrose standard (1 g sucrose/1000 ml water)
2. 30% KOH store in refrigerator (35.29 g solid 85% KOH, M wt 56.11 g in 100 ml H<sub>2</sub>O)
3. Anthrone reagent:
  - a. Prepare a diluted sulfuric acid solution by adding 76 ml H<sub>2</sub>SO<sub>4</sub> (analytical grade) *slowly* to 30 ml water while stirring and allow to cool.
  - b. Add 0.15 g anthrone to the distilled H<sub>2</sub>SO<sub>4</sub> solution. Mix well until dissolved (about 2 hours). Store in dark bottle in refrigerator.

**CAUTION: Avoid inhaling anthrone powder. Make sure the temperature of H<sub>2</sub>SO<sub>4</sub> solution is below 60° C before adding anthrone.**

**Work in well-ventilated area (under a hood)—do not pipet anthrone reagent by mouth.**

#### Procedure:

(Beaker, graduated cylinder, and water should be pre-chilled in refrigerator at 4° C.)

1. Weigh 200 g of cut pieces from four to five washed, peeled tubers.
2. Juicerate (using Acme Juicerator) and collect juice in a 600 ml beaker. Wash juicerator with 100 ml water three times. Wait 2 to 3 minutes between washings.
3. Transfer to 500 ml graduated cylinder — take volume to 430 ml with water.
4. Cover, mix, cool (4° C), and allow to settle for 1 hour.
5. Take portion and dilute one part extract with four parts water.
6. Prepare clean and dry tubes and fill them as follows:
  - a. To tubers No. 1 and 2, add 0.1 ml water (reagent blank, duplicate).
  - b. To No. 3, 4, and 5, add 0.1 ml of standard sucrose solution in each (0.1 ml = 0.1 ml sucrose and should read X = O.D.<sub>620</sub> gives 0.97 to 1.00).
  - c. To No. 6, 7, and 8, add 0.1 ml/tube of diluted potato extract (obtained from step 5 above).
7. Add 0.1 ml of 30% aqueous KOH reagent to each tube.
8. Mix, cover tubes with marbles, and heat at 100° C for 15 minutes (to destroy reducing sugars).
9. Cool to room temperature and add 3 ml anthrone reagent.
10. Cover tubes with parafilm and mix.

11. Incubate at 40° C (104° F) for 30 minutes if the anthrone solution is 1 week old or for 60 minutes if it is 1 month old.
12. Set colorimeter to zero with lowest reagent blank at 620 mm.
13. Read O.D.<sub>620</sub> of the stable yellowish-green color developed in the standard sucrose and unknown solutions.

**Calculation:**

$$\frac{\text{O.D. (Unknown} \times 0.1 \times 107.5 \text{ (Factor)}}{\text{O.D. (Standard) g Tuber}} = \text{mg Sucrose/g Tuber} = \text{Tuber SR (Sucrose Rating)}$$

Varieties with SR's of 2.5 or less (1.0 to 2.5 mg sucrose/g tuber) at harvest will produce acceptable chips from long-term storage (8 to 11 months) at 53° F.

**Peel and Defect Loss**

Peel and defect loss may be evaluated separately in operations designed to indicate the degree of peeling and trimming necessary in production.

The equipment and materials required for both the peeling and trimming loss methods are:

1. Scale to weigh in pounds
2. Abrasive peeler
3. Container large enough to hold 5 lb of potatoes
4. Water bath with spray for rinsing
5. Inspection belt or table
6. Trimming knives
7. 5 lb of washed potatoes

Determine the peeling and trimming losses as follows:

1. Weigh the empty container.
2. Weigh 5 lb of potatoes in the container.

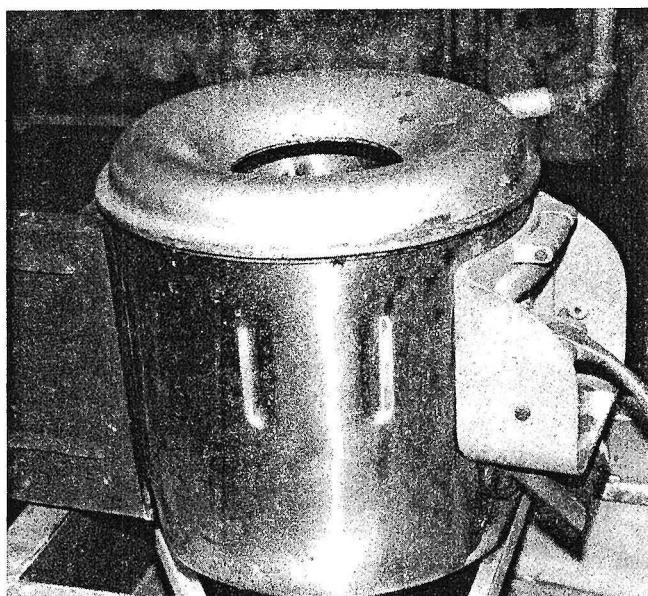


FIG. 5.—Peeler.

3. Place the potatoes in the empty peeler, operate peeler, collect them at the end of the peeler in the water bath, and rinse.
4. Drain off excess water from the potatoes.
5. Weigh the peeled potatoes and return immediately to water bath.
6. Calculate loss by the equation:

$$\frac{\text{Initial Weight—Peeled Weight}}{\text{Initial Weight}} \times 100$$

(If exactly 5 lb of potatoes are used, the percent peeling loss may be calculated by multiplying the pounds lost in peeling by 20.)

7. Move peeled potatoes to inspection belt or table.
8. Trim to remove remaining peel and defects.
9. Weigh the remaining potatoes.
10. Calculate the trimming loss as follows:

Percent Trimming Loss =

$$\frac{\text{Peeled Weight—Trimmed Weight}}{\text{Peeled Weight}} \times 100$$

**POTATO CHIP TESTS**

The manufacture of acceptable quality chips is accomplished through a series of operations. Each chip manufacturer may vary the operations slightly depending on equipment, but generally all follow similar procedures and control of the operations. The washing, peeling, and trimming operations have already been discussed. Following trimming, the potato cultivar is evaluated during slicing and frying.

**Slicing**

Slice thickness will vary depending on the market demand of the chipper. However, for purposes of cultivar evaluation, the slicer should be set for a slice thickness of 0.063 inch or approximately 16 slices to the

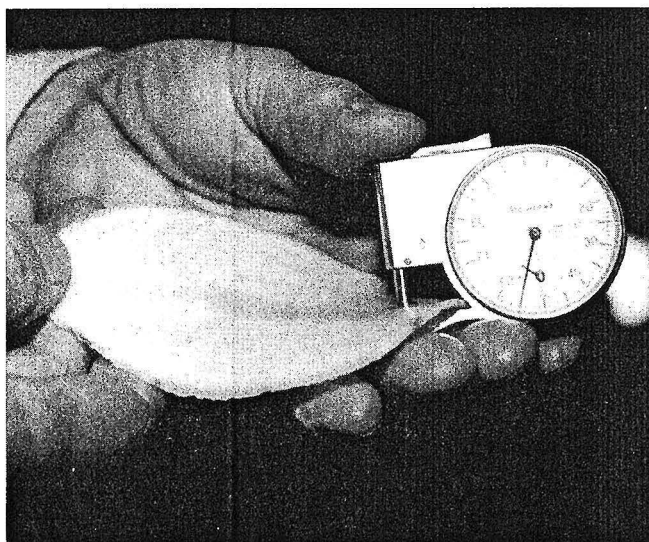


FIG. 6.—Slice thickness measurement.

inch (Fig. 7). The knives must be sharp and any slices not cut at the same thickness should be discarded since they will not fry uniformly. Variations in slice thickness may be observed by holding washed slices up to a light. Following slicing, the slices should be washed to remove starch from the cut surfaces and then drained to remove excess moisture.

### Frying

Frying chips is a very precisely controlled unit operation. The operator has many variables to control (time, temperature, rake speed, moisture content, etc.), but for purposes of cultivar evaluation these should be held constant. Two basic frying methods are used — the kettle method and the continuous fry method (Fig. 8). Regardless of the method used, the fryer should be thermostatically controlled and should hold sufficient good quality oil to allow a standard size sample (1/2 lb minimum) a temperature drop of approximately 11° C (20° F) from the time the chips are placed in the oil until they are fried. That is, the fryer should be preheated to 188° C (375° F); with the correct sample size, the temperature should drop to 177° C (355° F) while the chips are in the oil. If the fryer temperature is higher, the finished chips will be darker in color. If the temperature falls

lower than 177° C (355° F), excessively light colored and possibly soft centered chips will be produced.

Time in the fryer will vary with the specific gravity of the slices and the slice thickness. Using slices of 1.080

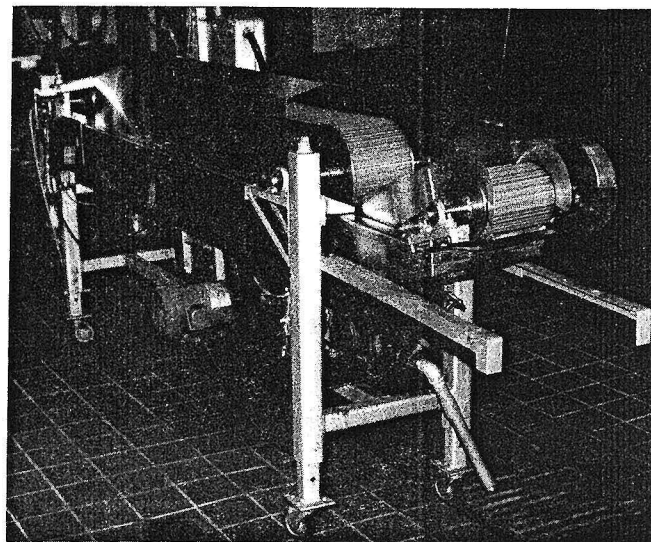


FIG. 8.—Model continuous fryer.

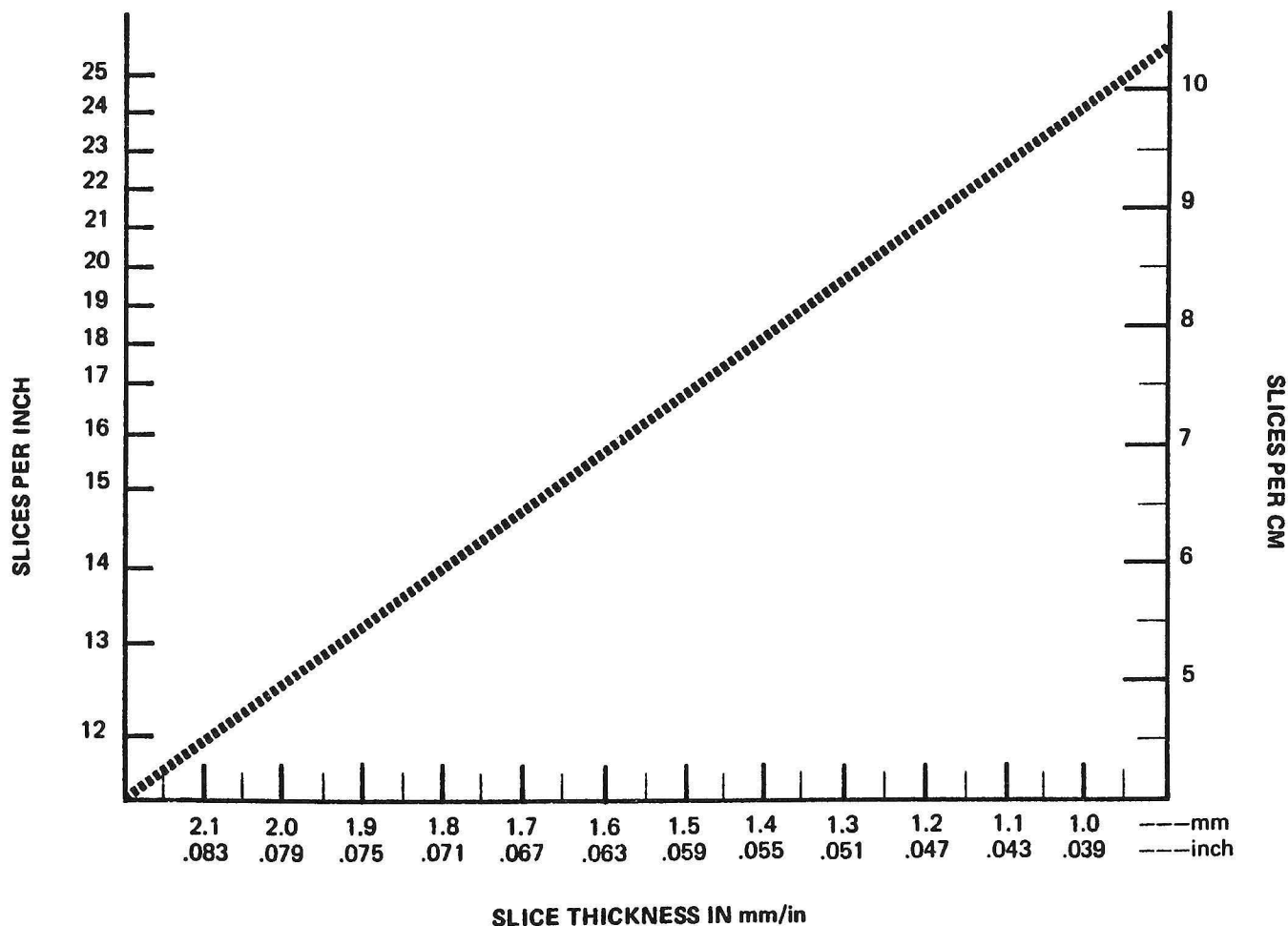


FIG. 7.—Relationship of slices per inch or per cm to slice thickness.



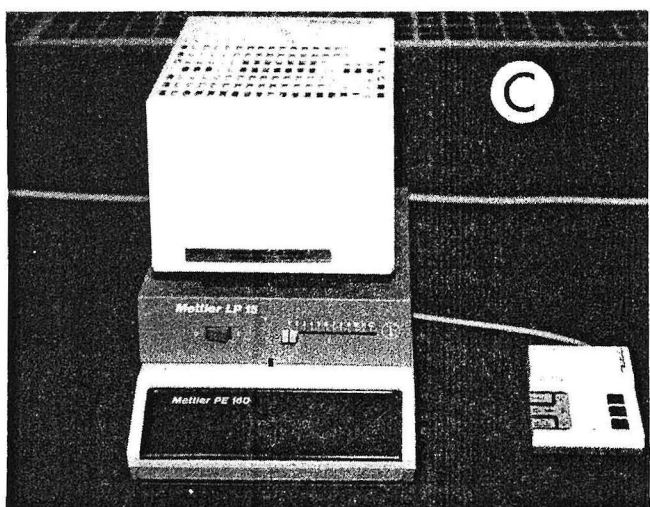
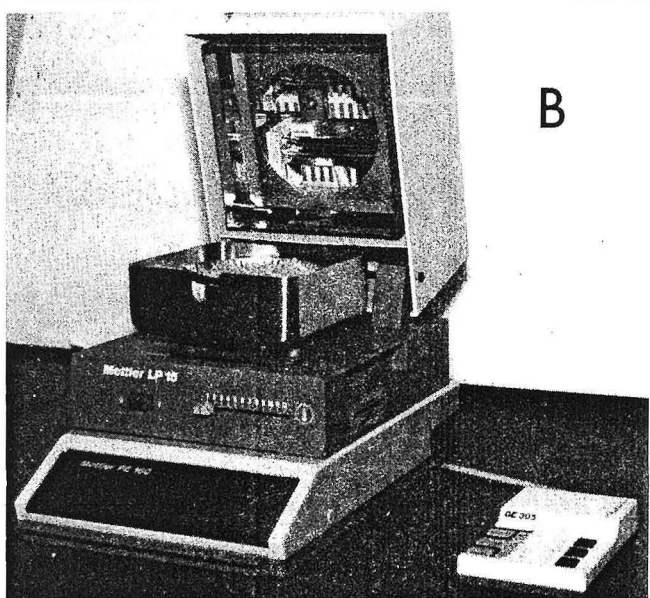
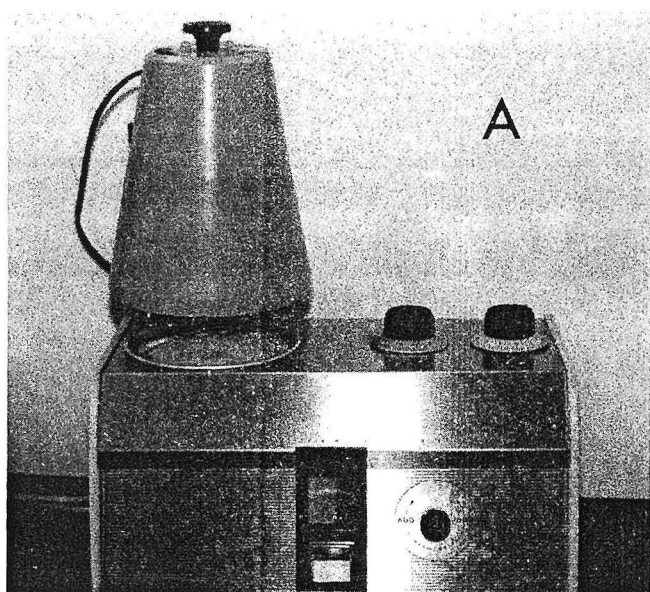


FIG. 9.—Infrared moisture balances. A. Ohaus; B. Mettler opened; C. Mettler closed.

specific gravity, a slice thickness of 0.063 inch and a fryer set at an inlet temperature of 188° C (375° F), the time in the fryer should be approximately 130 seconds (exact time determined by trial and error). The moisture content should be  $2 \pm 0.25\%$ . Samples above 2.25% moisture will not have a good shelf life and the true chip color may not have been properly developed.

When preparing to fry chips for cultivar evaluation, the question may be asked as to what type of oil to use. Types of oil vary by market area since the type of oil will determine in part the flavor of the chip. A good quality oil, clear and of good bland flavor, commonly used for chip manufacture is recommended. The oil should be relatively free of free fatty acids. Oil should never be used if the free fatty acid content is greater than 1% for good flavored chips. Oil filtration should be performed daily to assure a clear oil, free of particles. Further, the oil should be stored in non-transparent containers and without air in the head space.

### Moisture

The moisture content of potato chips is an index of the quality of the product as well as an index of processing efficiency. For potato cultivar evaluation, controlling the final moisture content to  $\pm 0.25\%$  eliminates variation in samples which may otherwise make quality comparisons between cultivars erroneous. The standard drying oven and toluene distillation methods are very accurate but several quick methods more applicable to online control have been proposed in recent years. The quick methods, such as the infrared moisture balance, should be used to determine quickly the moisture content of potato chips. Calibration with the vacuum oven or other more precise methods will assure correct readings.

### Infrared Moisture Method

#### General

Moisture content can be determined quickly using a top loading balance with an attached infrared heating element (Fig. 9). This provides continual indication of weight decrease and percent of moisture loss throughout the drying cycle until a constant weight is obtained. This method is not as precise as the Vacuum Oven Method but it is rapid. With care in application, it gives a good indication of sample moisture.

Care must be used in standardizing the lamp height, heating time, and size of bulb. The chips or snacks should be ground or broken up into small pieces.

#### Equipment:

1. Top loading balance
2. Infrared heating element
3. Drying dishes
4. 5 to 10 grams of potato chips

#### Procedure:

1. Accurately weigh a representative 5 to 10 gram sample into a weighing dish directly on the balance.

2. Turn on lamp and leave on until no further change in weight occurs.
3. Record weight every 15 seconds on the following form until a constant weight is established, and then calculate the moisture content (Form 1).

**Form 1.—Determination of Moisture Content.**

Time (sec)	Readings (g)	Time (sec)	Readings (g)	Time (sec)	Readings (g)
0	_____	210	_____	405	_____
15	_____	225	_____	420	_____
30	_____	240	_____	435	_____
45	_____	255	_____	450	_____
60	_____	270	_____	465	_____
75	_____	285	_____	480	_____
90	_____	300	_____	495	_____
105	_____	315	_____	510	_____
120	_____	330	_____	525	_____
135	_____	345	_____	540	_____
150	_____	360	_____	555	_____
165	_____	375	_____	570	_____
180	_____	390	_____	585	_____
195	_____			600	_____

Percent Moisture =

$$\frac{\text{Weight of Sample} - \text{Weight of Dried Sample}}{\text{Weight of Sample}} \times 100$$

Percent Moisture = \_\_\_\_\_

**Vacuum Oven Method (Fig. 10)**

**Equipment**

1. Mortar and pestle
2. Twenty-mesh screen
3. Two drying dishes (15 x 90 mm)
4. Vacuum oven
5. Balance

**Procedure:**

1. Grind sample to pass through 20-mesh screen and mill thoroughly (if sample cannot be ground, cut into small pieces). Note: The sample should be ground quickly in a room with low relative humidity to prevent moisture uptake from the atmosphere.
2. Spread 20 grams of the prepared sample as evenly as possible over bottom of weighing dish, cover, and weigh accurately to second decimal place. (Run duplicate samples.)
3. Dry at 70° C (158° F) for 6 hours under 26 inches of vacuum. During drying, admit a slow current of air into the oven (about two bubbles per second) dried by passing through concentrated sulfuric acid.
4. Cool in desiccator for 30 minutes and reweigh.
5. Calculate the moisture content of the sample.

Percent Moisture=

$$\frac{\text{Weight of Sample} - \text{Weight of Dried Sample}}{\text{Weight of Sample}} \times 100$$

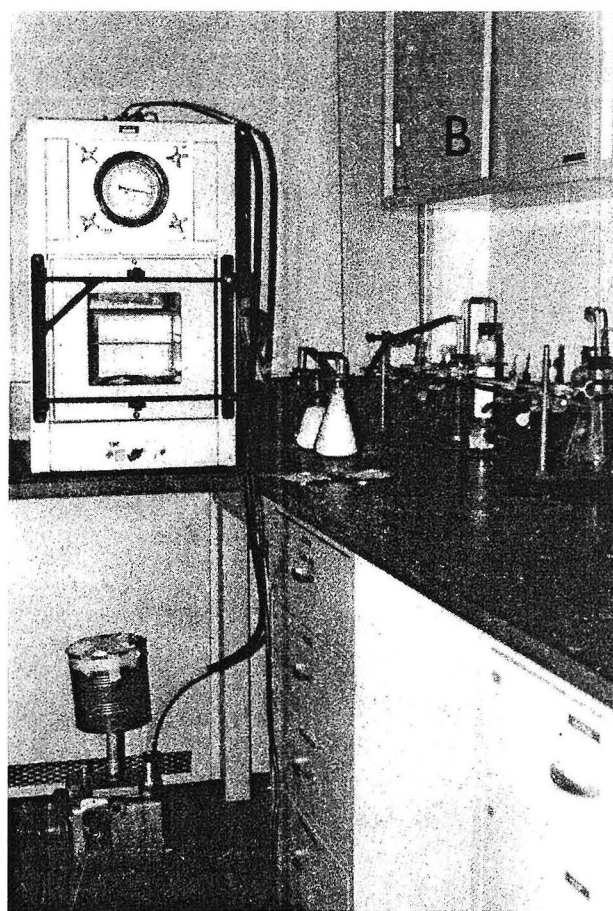
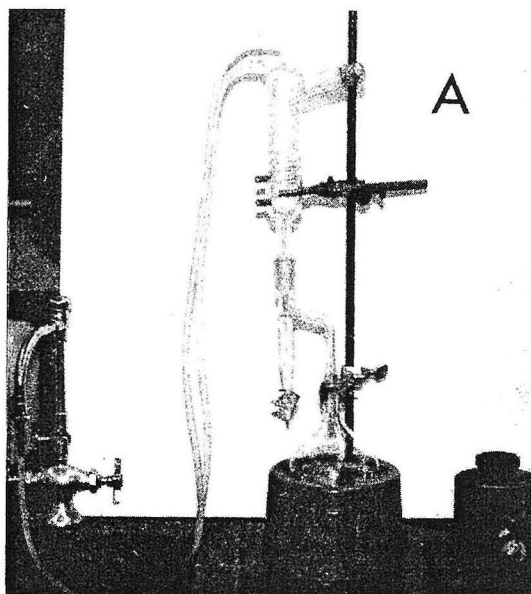


FIG. 10.—A. Toluene distillation moisture apparatus; B. vacuum oven for moisture determination.

## ***Toluene Distillation (Fig. 10) Moisture***

### **Equipment**

1. Flask
2. Sterling-Bidwell graduated collection tube
3. Condenser
4. Toluene

### **Procedure:**

1. Weigh a 100-gram sample (sample should give 2-5 ml of water).
2. Add to the flask and cover immediately with toluene.
3. Connect the apparatus with cork stoppers (covered with tin foil) and fill the Sterling-Bidwell graduated collection tube with toluene (pour it through the top of the condenser and allow a few ml to flow over into the flask).
4. Bring to a boil and distill slowly (two drops per second) until most of the water has passed over (about 20 minutes). Now increase the rate of distillation to four drops per second.
5. Stop distillation when no more water collects in the collection tube. Then wash the inside of the condenser with toluene to deliver all condensed water to the graduated arm.
6. Cool water column to room temperature and read directly the ml of water collected. (For all practical purposes, this is numerically equal to the grams of water collected.)
7. From the weight of the sample and the weight of the water collected, compute the percentage of moisture in your sample.
8. Record results

### **Yield**

The yield of potato chips for a particular cultivar can mean success or failure to a chipper. Final yield depends not only on peel and trim loss, but also specific gravity and cultivar. To obtain potato chip yield, the sample should be weighed prior to slicing. Another sample weight may be required after slicing if a large number of the slices are too small or not sufficiently uniform for frying. A final weight of the finished chips may be taken after the sample has cooled. Care must be taken to avoid the loss of slices in some continuous fryers. The percentage yield may be calculated by:

Percent Yield =

$$\frac{\text{Initial Weight} - \text{Final Weight}}{\text{Initial Weight}} \times 100$$

Note: This calculated yield does not take account of oil absorbed by the sample. True yield for purposes of cost estimation must factor in the oil absorbed or consumed by the sample.

### **Color**

Color is one of the most important factors in the quality evaluation of nearly all food products and

accounts for 30% of the final product quality under a quality standard for potato chips proposed by the senior author. An important problem in the potato chip industry is the maintenance of desirable color of chips throughout the year. Factors influencing potato chip color are cultivar, growing environment, fertilization, maturity, storage temperature, temperature of oil, thickness of slice, and length of frying time. By controlling the maturity, storage temperature, temperature of oil, thickness of slice, and length of frying time, one may determine the effect of each cultivar on potato chip color.

Color can be measured subjectively, but preferably should be done objectively. The PC/SFA subjective color chart is a good, quick, subjective benchmark of chip quality. For research purposes, spectrophotometric methods are preferred. The Agtron M-30 (Fig. 12) measures the relative spectral characteristics of non-homogeneous and particulate colored products, which are important factors in the measurement of potato chips. The capability of the M-30 to provide accurate and reproducible measurements of such products is based on concentric diffuse illumination of a 30 in<sup>2</sup> sample. The reflected light from the sample represents an average color character of the sample which is largely unaffected by particle size, particle geometry, irregularities, voids, and shadows.

The Agtron E-5F (Fig. 11) is a direct reading reflectance colorimeter which has recently gained popularity in the potato chip industry. The design provides the ratio of reflectance of a product in two spectral modes, infrared and green. Like the M-30, this instrument is accurate and repeatable, and measures the average color character of non-homogeneous and particulate colored products. The E-5F views the sample from above and displays the standard calibrated reading when the drawer is open. The E-5F has the additional advantage of being sufficiently small and light in weight to make on-site color evaluation more feasible. The sample cup and sliding drawer also simplify clean-up.

### ***PC/SFA Color Comparison***

#### **Equipment:**

1. PC/SFA fry color standards for color designations 1-5.

#### **Procedure:**

1. Select a minimum of 20 slices and under standardized daylight lighting conditions rate color of chips according to color designations 1-5.
2. Record results

### ***Agtron M-30A Method***

#### **Equipment:**

1. Agtron M-30A-M400A (Magnuson Engineers, Inc.)
2. Zero calibration disk
3. Ninety calibration disk
4. Sample cups



#### Procedure for M-30A - M-400A:

1. Make sure M-30A is plugged into M-400A.
2. Turn power switch to the M-30A position and allow the instrument to warm up 1 hour for most stable operation.
3. Obtain the desired "zero" (M-00) and "90" (M-90) calibration disks. Select the desired spectral mode (red mode recommended for chips) and set the selector on the M-30A - M-400A unit.
4. Place sample cup on M-30A and insert the "zero" calibration disk.
5. On the M-400A, set the Gain Control at minimum (full counterclockwise) and adjust the "zero" control for a meter reading of the same value as the "zero" disk.
6. Remove the "zero" disk and place the "90" disk in the sample cup and adjust the Standardized Control for a meter reading of 90.
7. Recheck setting by repeating steps 4, 5, and 6 and remove calibration disks.
8. Place sufficient sample to fill cup level full, place on the viewer area, and record the meter readings.

#### Care of Calibration

Agtron sample cups should also be handled carefully to avoid scratches. Place cup on soft cloth or tissue. Keep disks and cups clean. Wash with mild detergent in warm water, rinse, and dry with soft cloth or tissue.

#### Agtron E-5F

##### Equipment:

1. Agtron E-5F (Magnuson Engineers, Inc.) with black metal sample cup.

##### Procedure:

1. Push power switch button on and allow 1 hour to warm up for stable readings. Make certain the scale is placed in the XI position. If samples are

extremely warm, the fan should be used to prevent overheating of the unit.

2. To standardize the instrument, pull drawer completely out and allow reading to stabilize (about 5 to 10 seconds). Adjust to a meter reading of 100.
3. Close drawer. Recheck by repeating step 2.
4. Place sample in cup, making sure entire surface is covered. Do not overfill. This may cause chips to catch on frame and become either broken or pulled to one side of sample cup.
5. Record Agtron value.

##### Interpretation:

Using the Agtron E-5F vs. the Agtron M-30A, a correlation of 0.999 was obtained. The data in Table 6 show this relationship.

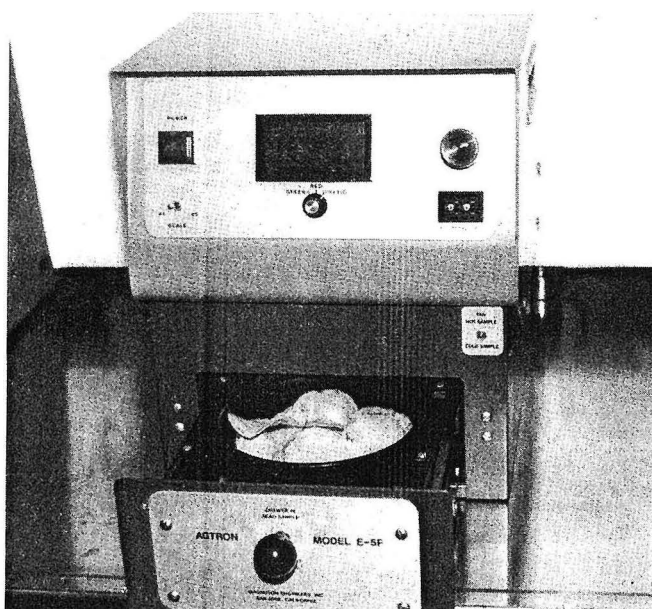


FIG. 11.—Agtron E-5F.

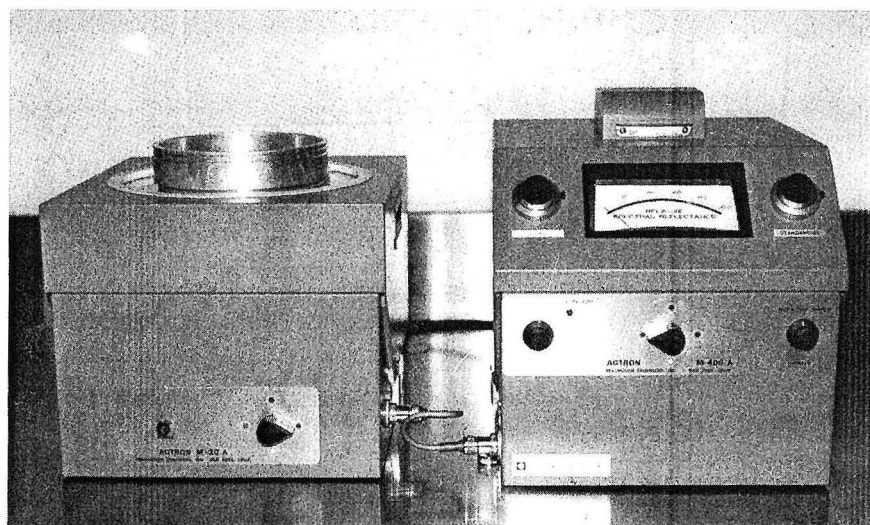


FIG. 12.—Agtron M-30.

**TABLE 6.—Relationship of Color Score to Agtron Values.**

New PC/SFA Color Scores	Agtron M-30 Red Value	PC/SFA Agtron E-5F Ratio Color	Old PC/SFA Color	Grade Scores
1	65 and higher	61-70	1.5- 3.0	25-30
2	55-64	50-60	3.0- 4.5	21-25
3	45-54	39-49	4.5- 6.0	11-20
4	35-44	28-38	6.0- 7.5	6-10
5	less than 34	less than 28	7.5-10.0	0-5

## Oil Absorption

Oil absorption on chips should be less than 46% and preferably as low as 30%. The amount of oil will vary depending on the specific gravity of the tubers, slice thickness, types of oils, and frying conditions. Since the other factors are carefully controlled during cultivar evaluations, the specific gravity of the tubers should be the only factor to influence the oil content of the chips. Relying on the specific gravity alone as an indicator of the oil content of chips produced from a cultivar could be misleading. Therefore, the oil content should also be carefully determined and should be made on fresh (same day as chipped) chips only.

## *Bailey-Walker (Soxhlet) Method (Fig. 14)*

### Equipment and Materials:

1. Balance
2. Mortar and pestle
3. Cylinder
4. Petroleum ether
5. Electric air oven
6. Condenser vials
7. Paper thimbles

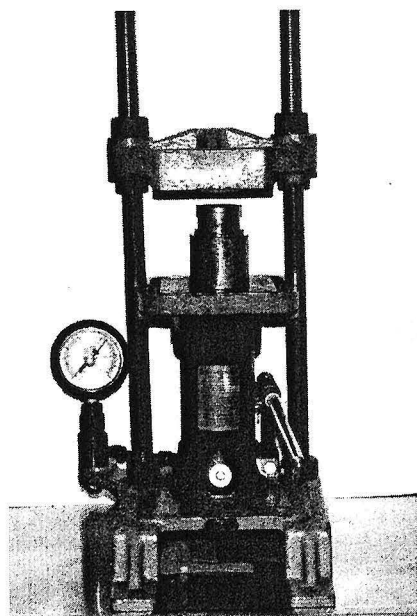


FIG. 13.—Carver press for oil extraction.

8. Electric hot plate

9. Condenser with water circulating system

### Procedure:

1. Weigh oven-dried thimble.
2. Using a mortar, grind the sample.
3. Weigh out a 10-gram sample.
4. Place 10-gram sample in preweighed thimble.
5. Add approximately 40 ml of petroleum ether to condenser vial and then place the thimble with 10-gram sample into the vial. Use enough ether to fill up the vial just below the top of the thimble (approximately 1/4 inch).
6. Turn hood on and start the water circulating through the condenser. *Important*—Check to make sure the hood is operating and the water is circulating through the condenser.
7. Turn the hot plate on high until the samples begin to boil; then turn the hot plate to a temperature to allow good refluxing for 1 hour.
8. At the end of 1 hour, remove the thimbles and dry them for 30 minutes in an air circulating oven at 100° C.

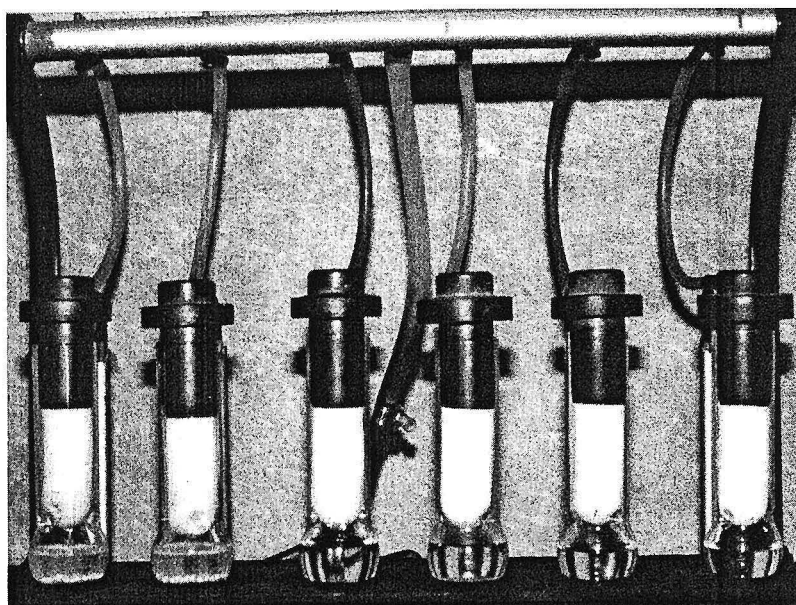


FIG. 14.—Bailey-Walker ether extraction.

9. Weigh the thimbles and extracted samples and calculate the weight of oil absorbed.
10. Divide weight of oil by weight of sample used and report as percentage of oil.

$$\text{Percent of Oil} = \frac{\text{Weight of Oil}}{\text{Weight of Chips}} \times 100$$

#### Interpretation:

The QMC (Quartermaster Corps) has a maximum tolerance of 46%. Good quality chips have an oil content of  $35 \pm 5\%$ .

#### Testing for Percent Fat by Using the Carver Press Method (Fig. 13) as Modified

##### Equipment:

1. Carver press
2. Paper towels
3. Triple beam balance

##### Preliminary Preparation:

1. Grind 20 to 30 grams of the sample.
2. Thoroughly mix this sample to make sure the sample is consistent throughout.
3. Put three folded paper towels (standard size) in the bottom of the chamber to absorb the expressed oil.
4. Weigh 10 grams into the sample chamber.

##### Test Procedure:

1. Place the piston portion of the assembly on the sample and chamber.
2. Place the entire assembly in the press and pump it up at a rate of about one stroke every 2 seconds until 15,000 pounds of pressure is reached.
3. Allow 20 seconds for the pressure to drop off in the press and then pump it back up to 15,000 pounds of pressure.
4. Set the timer for exactly 3 minutes (180 seconds).
5. Do not pump the press up again even though the pressure may drop.
6. At the end of 3 minutes, release the pressure and remove the sample cake from the bottom side of the chamber, using care to include all cake portions and not include any oil portions in the weighing process.
7. Weigh the sample cake.
8. Read the oil content developed from ether extracts vs. press method for each type of oil used and record as such.

#### Quick Determination of Fat Content by Refractometer (Fig. 15)

##### Equipment:

1. Bausch and Lomb "Abbe 56" refractometer or equivalent. A constant temperature water bath maintained at  $30^{\circ}\text{C} \pm 2.5^{\circ}\text{C}$ . If it is not a circulating bath, a pump is needed. Water at  $30^{\circ}\text{C}$  should

be circulated through the refractometer for at least 30 minutes before readings are taken.

2. Torsion balance sensitive to 0.01 gram or equivalent
3. Explosion-proof Waring blender or equivalent
4. Glass funnels 2.5 inches in diameter
5. Whatman No. 1 filter paper, 12.5 cm
6. 50 ml Erlenmeyer flask or equivalent as filtration receivers
7. Glass eye dropper
8. 50 ml pipette, burette, or equivalent to measure and deliver n-Heptane

##### Reagents:

1. n-Heptane — Phillips Petroleum Co. "Pure Grade"  $96^{\circ}\text{C}$  ( $209.1^{\circ}\text{F}$ ) boiling point, refractive index 1.3840 at  $30^{\circ}\text{C}$ . Flammable — use with care. Refractive index of each batch of n-Heptane should be checked to be sure that it is normal and calibrated by following the procedure below and charting the data similarly to the data in Table 1.

##### Procedure:

1. Weigh 50 grams of representative sample of chips; transfer to Waring blender jar.
2. Add 50 ml n-Heptane to jar.
3. Mix slowly for 1 minute or until chips are chopped up and mixed into solvent. If trouble is

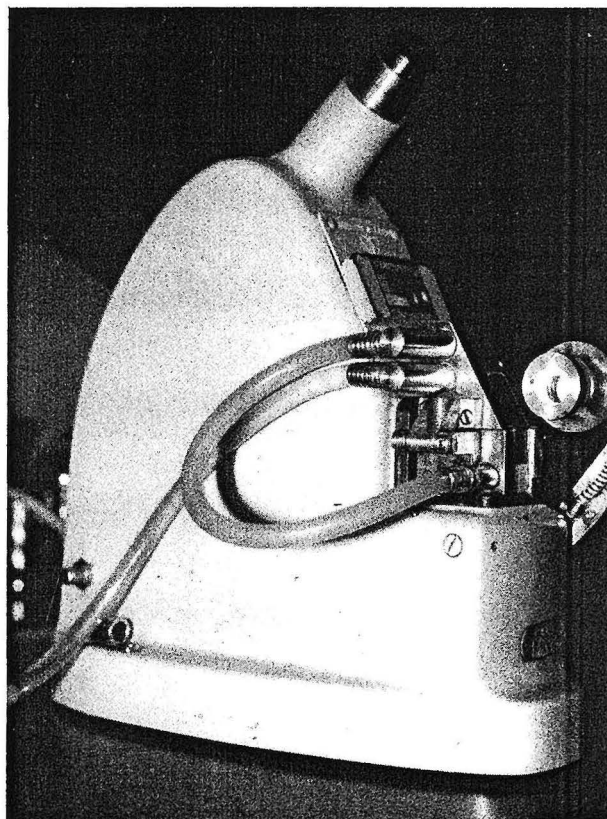


FIG. 15.—Refractometer.

encountered with too low volume at this stage, 60 grams of chips and 60 ml of n-Heptane or any other quantities may be used as long as the ratios are kept one to one. Do not spill any solvent on

**TABLE 7.—Relationship of Percent Fat to Refractive Index.**

Percent Fat	Refractive Index 30° C*
25	1.2993
30	1.4010
35	1.4042
40	1.4062
45	1.4079
50	1.4094

\*If temperature control is not used, a correction factor of 0.0004 should be subtracted from the refractive index reading of an unknown extract for each degree centigrade in temperature of the extract below that of the temperature used in establishing the standard chart and curve. If the temperature of the extract is higher than that used in establishing the curve, 0.0004 should be added to the refractive index of the extract for each degree centigrade difference.

blender motor. Be sure blender jar motor bearings do not leak.

- Mix at high speed for 2 minutes with loose lid on blender.
- Decant some of the extract into filter paper in funnel. Have funnel in cork in Erlenmeyer and place a watch glass on the funnel during filtration to minimize evaporation.
- If first part of filtrate is cloudy, discard; collect a few ml of clear filtrate.
- Place two or three drops of clear extract on refractometer prisms to cover.
- Close prisms, allow extract approximately 20 seconds to come to temperature, and read refractive index.

#### Calculations:

From the standard curve or chart (see below) prepared with the frying fat in use, convert refractive index directly to percent fat of chips.

#### Standard Curve or Chart:

Calibration curves can be developed directly by adding to 50 ml n-Heptane an equivalent amount of fat found in a 50-gram sample of chips. Example: 40% fat would require 20 grams of fat added to 50 ml n-Heptane. A number of solutions of different fat content may be prepared in this way. The refractive index of each solution is plotted against the percentage of fat based on 50 grams of chips in each solution as the source of fat. The relationship of percent fat to refractive index is given in Table 7.

A separate standard curve or chart is needed for each frying fat, as fats may differ in refractive index. A chart may be prepared by listing a series of percentages of fat with the corresponding refractive indices.

#### Defects

Defects in chips refer to pieces of peel, green discoloration, internal discoloration of the slice, or other harmless extraneous materials. Although not normally listed as defects, blisters are troublesome from an appearance standpoint. Blisters develop during the frying operation and studies at the OSU laboratories indicate that blisters are, in part, related to the potato cultivar. Defects and waste are costly; therefore, every effort should be made to ensure that a new cultivar will not contribute to this problem.

#### Testing for Freedom from Defects

##### Equipment:

- Two-quart sample container
- Major and minor defect sample display (Figs. 16 and 17)

##### Procedure:

- Fill sample container with chips to be tested.
- Examine chips visually and separate any chips which show defects.

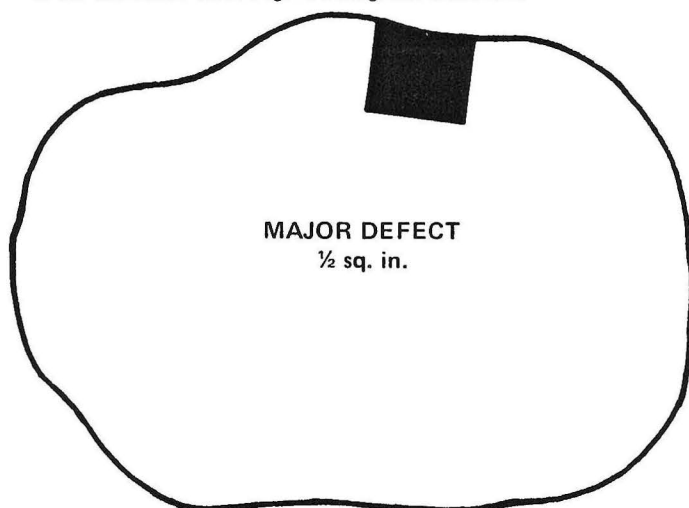


FIG. 16.—Major defect (1/2 sq in).

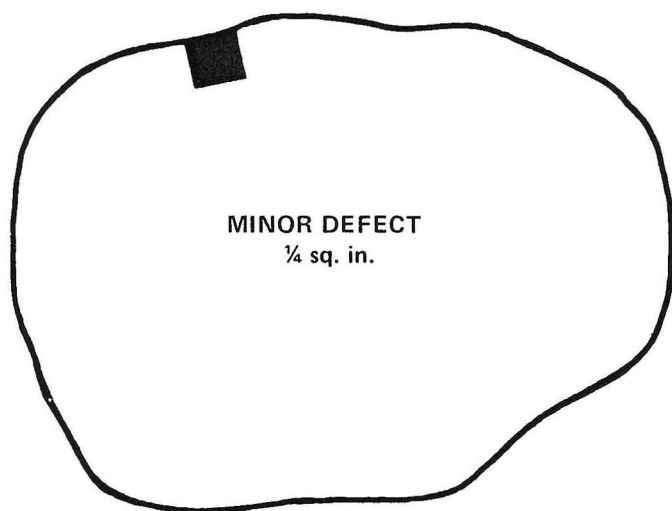


FIG. 17.—Minor defect (1/4 sq in).



3. Separate defects into minor and major classes and calculate the percentage of chips for each class (Table 8).
4. Do not count more than two major defects on any one chip; for example, a chip with two major defects is counted as two, a chip with three or four major defects is counted as two.
5. If a chip has a wet center and a major defect, it is counted once for each test. The wet center is not counted as a major defect.
6. Record results.

### Testing for Blisters

#### Equipment:

1. Two-quart sample container
2. Blister sample (Fig. 18)

#### Procedure:

1. Fill sample container with chips to be tested.
2. Examine chips visually and separate any chips which show significant blisters (greater than 20 mm circle) (see Fig. 18).
3. Count number of significant blisters and calculate the percentage of blistered chips.

### Hash and Bulking

The amount of hashed chips or crumbs in the finished and packaged chips is considered one of the most important defects of chips by many consumers. Hash in potato chips is pieces or broken chips 1 inch square or smaller. Hashing detracts from bulking of the product and is highly undesirable to consumers. Bulking is dependent in part on the slice size and fryer operation, but cultivars can be a factor in bulking.

To determine the hash, the sample should be packaged. A form and fill pilot scale packaging unit is preferable for replicating commercial conditions. Hand filling of bags is acceptable provided care is taken not to excessively damage chips or to select only the large chips. Each package should be 2 to 3-1/2 oz. in weight. If packaging materials and equipment are unavailable, simply use a 100 gram sample of the finished chips.

### Percent Hash in Packages

#### Equipment:

1. Balance

#### Procedure:

1. Select a package of chips or a minimum of 100 g sample of finished chips.
2. Empty the package and weigh the contents.
3. Separate chips from hash and crumbs. Hash is anything smaller than 1 in<sup>2</sup> in area (Fig. 19).
4. Weigh hash and crumbs.
5. Divide weight of hash and crumbs by original weight and report as percent.

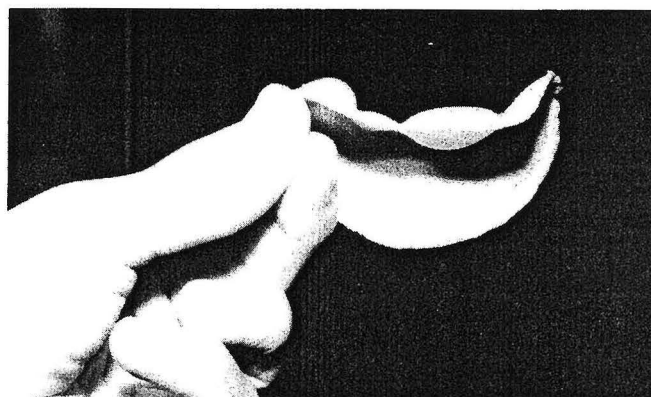
Example:  $\frac{15 \text{ g Hash}}{100 \text{ g Total}} \times 100 = 15\% \text{ Hash}$

**TABLE 8.—Classification of Defects into Minor (Fig. 16) and Major (Fig. 17) Categories.**

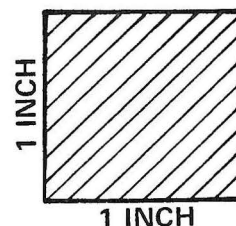
Defect Classification	Minor	Major
<b>Group I</b>		
Discolored appearance which adversely affects the chip to a noticeable degree, i.e., 1/4 square inch or less.	X	
Discolored appearance which adversely affects the chip to a degree which is objectionable; i.e., more than 1/4 square inch in area.		X
<b>Group II Defects</b>		
Blemished area including peel, internal discoloration, or harmless extraneous material which adversely affects the chip; i.e., 1/4 square inch or less.	X	
Blemished area including peel, internal discoloration, or harmless material which seriously affects the chip; i.e., more than 1/4 square inch in area.		X

**TABLE 9.—Relationship of Defects to Quality Classification and Score.**

Quality Class	Score	Maximum Number of Defects	
		Minor	Major
1	18-20	0-5	0-3
2	16-17	6-10	4-5
3	11-15	11-15	6-8
4	6-10	16-20	9-12
5	0-5	more than 20	more than 12



**FIG. 18.—A significant blister is larger than 20 mm circle or approximately the size of a nickel.**



**FIG. 19.—Hash.**



FIG. 20.—Numerical scoring form.

[illegible]

Write the following letters in the corresponding column or columns (F) Flavor and (T) Texture.

Signature \_\_\_\_\_

## Bulking in Packages

### Equipment:

1. 500 ml beaker
2. Balance

### Procedure:

1. Select a package of chips or a 100 g sample of finished chips.
2. Weigh the chips.
3. Empty the package into a 500-ml beaker and record volume.
4. Calculate the specific volume and report as ml/g.

$$\text{Example: } \frac{450 \text{ ml}}{85 \text{ g}} = 5.3 \text{ ml/g}$$

## Flavor and Texture

At present both flavor and texture are evaluated subjectively. Off-flavors could be an inherited trait similar to the glycoalkaloids found in some cultivars. Poor texture could be the result of too high or too low specific gravity, improper slicing, or poor frying. All of these conditions could be cultivar-related and need to be included in the evaluation of new cultivars.

Flavor evaluation should be conducted by a panel of trained tasters, consisting of at least seven members. No one person should have the sole responsibility of judging a sensory characteristic. The combined judgment of several people will minimize any individual sensitivity variation or fluctuation through the day and from day to day.

Tasting should be conducted in an odor-free, natural daylight lighted room and each panelist should not divulge his evaluation of the sample to any other panelist until each has recorded his decision.

## Numerical Scoring Taste Evaluation

### Procedure:

1. Prepare and code seven samples for panel members (one complete set for each panel member) at every individual setting.
2. Place two or three chips from the coded sample into a coded clean dish, place on a tray, and distribute to flavor booths with score card (Fig. 20), an empty cup for mouth rinsing, and a glass of water.
3. Notify panel members that the panel is ready and instruct them to score the samples for flavor first and then texture, using the 10-point scoring system.
4. Allow each judge as much time as he/she requires.
5. Check to see that each judge is marking the evaluation card correctly and that he/she has signed it when finished.
6. Tabulate the data from the cards.

Generally it is advisable to duplicate the taste panel session to test the members' ability to repeat themselves. When this is done, duplicate samples should never be

TABLE 10.—Quality Scores of Potato Chips.

Factors of Quality	A	B	C	D
Color	26-30	21-25	11-20	6-10
Absence of Defects	19-20	16-18	11-15	6-10
Texture	19-20	16-18	11-15	6-10
Flavor	26-30	21-25	11-20	6-10
Minimum Total Score	90	74	44	18

given to the panel with the same codes. In other words, the panel should be conducted in a blind manner.

### Interpretations:

The data should be statistically analyzed to determine if there are real differences. When there are more than two different samples, the most applicable method is the analysis of variance (ANOVA) with mean separation.

## FROZEN FRENCH FRY TESTS

The most important factor in frozen french fry production is the proper selection of suitable raw material. Not only must the potatoes be suitable for processing, but because of the seasonal nature of the crop, stock may be held nearly year-round to meet production schedules. Currently, the demand for raw materials often means utilizing immature and field-run materials. While using field-run potatoes has eliminated a handling operation, they may potentially increase loss from bruising; processors have had to include the manufacture of hash browns and similar products to make use of the shorts and splinters which necessarily accompany frozen french fry production of small potatoes.

Cultivar selection is considered to be the primary factor influencing frozen french fry quality. The development of high quality, early varieties will help alleviate some problems, but evaluation is required to ensure raw materials which will provide uniform, long, crisp, and rigid cuts for french fries. Frying tests for new cultivars are regarded as the most reliable guide for the selection of potatoes for processing.

French fries generally require high specific gravity potatoes which yield fries of mealy texture. Other factors considered in french fry quality are color, oil content, tenderness, crispness, and flavor. The evaluation of the raw tuber was discussed earlier. In this section, the control of processing conditions for frozen french fries and methods of evaluation are covered.

## Cutting

The cutting unit operation follows washing, peeling, and trimming. In this operation, the goal is to produce long, uniformly cut strips for frying. The size of french fry cuts varies from producer to producer; however, a 1/4 to 3/8-inch square cross section is common. To aid in data comparisons, a 1/4-inch square strip is recommended for cultivar evaluation. For this

purpose, a high speed strip cutter may be used, but manual vegetable cutters or similar equipment could be substituted. Care must be taken to align the potatoes along the long axis in order to obtain the greatest yield of long cuts. Like potato chips, a uniform cross section should be maintained to prevent uneven frying.

Immediately after cutting, short loss may be determined by separating shorts and slivers from the long cuts.

### **Short Loss Evaluation**

#### **Equipment:**

1. Balance
2. Two-quart sample container

#### **Procedure:**

1. Weigh sample container to obtain tare weight.
2. Weigh raw, peeled, and trimmed potatoes (at least 10 lb).
3. Cut.
4. Separate shorts and slivers from strips. A short is any strip less than 1/2 inch long. A sliver is any strip less than 3/16 x 3/16-inch in cross section.  
*Note:* Tapering at end of a strip is acceptable.
5. Weigh shorts and slivers.
6. Calculate the percent shorts loss as follows:

$$\frac{\text{Weight of Shorts and Slivers}}{\text{Initial Wt. of Potatoes}} \times 100 = \text{Percent Short Loss}$$

Shorts and slivers should not exceed 10%.

### **Blanching**

Water blanching of french fry strips prior to frying inactivates enzymes, which may cause surface browning, and provides leaching of the reducing sugars, which could cause non-enzymatic browning. The effect is a lighter, more uniform color with less fat adsorption. Although dry blanching is now being used by some processors, a water blanch is acceptable for cultivar evaluation. Using either a continuous water blancher or a kettle, the french fry strips should be treated for 3 minutes at a temperature of 85° C (185° F).

### **Par-frying**

A majority of the frozen fries sold today are prepared for consumption by a sho finish fry at the point of consumption. The processor par-fries the strips before freezing, thus creating a product which requires a short finish fry. As with potato chip production, careful regulation of the frying operation assures a crisp product with uniform color. Full color development, however, does not occur at this operation.

Both single stage and double stage frying operations are employed by the industry for par-frying. Although the double-stage system has many advantages, a single stage system is suitable for new cultivar evaluation. Uniformity of color may be accomplished by agitating the strips during frying. Careful control of temperature and time will prevent surface separation, over or under-

cooking, or inadequate or excessive oil uptake. Whether the operation is continuous or batch-method, the initial or inlet temperature should be maintained at 190° C (375° F) and fall to a minimum final or outlet temperature of 180° C (355° F) after 90 seconds. Longer periods of frying result in increased oil content and reduced yield. The par-fry operation is followed by draining off (20 seconds) excess fat. This may be accomplished by either shaking the fries up and down in a wire basket or by conveying them over a vibrating screen.

### **Freezing**

The freezing operation can be a critical factor influencing the quality of the finished product. Simulating commercial conditions requires a rapid freezing process which will result in minimum crystallization and loss in texture. Ideally, a blast freezer which can freeze the strips individually at -4° C (-40° F) in 12 minutes is suggested for cultivar evaluation.

For the processor, yield is an extremely important characteristic. Calculation of the yield involves weighing the frozen sample and using the following equation:

$$\text{Percent Yield} = \frac{\text{Weight of Frozen Sample}}{(\text{Weight of Raw Potatoes} - \text{Weight of Shorts})} \times 100$$

### **Moisture Content**

The moisture content of frozen french fried potatoes will affect the texture in the finished product. Determination of the moisture content should be done after par-frying and after finish frying, using the vacuum oven method.

### **Oil Content**

The oil content of par-fried french fries should be near 4% before freezing and 5 to 7% after freezing (due to change in moisture level during freezing). Excessive oil will detract from the texture of the fry and increase limpness. Oil content should be determined by the ether extraction method described below.

#### **Oil Content**

##### **Equipment:**

1. See Vacuum Oven Method, pg. 11.
2. See Bailey Walker Method, pg. 14.

##### **Procedure**

1. Dry sample as described in Vacuum Oven Method.
2. Follow Bailey-Walker Procedure steps 1-9.
3. Calculate oil content on a dry basis by the following equation:

$$\frac{\text{Wt. of Dry Sample} - \text{Wt. of Extracted Sample}}{\text{Wt. of Dried Sample}} \times 100 = \text{Percent Oil Content}$$

4. Conversion of oil content on a wet basis may be accomplished by obtaining the previously deter-

mined moisture content and calculating as follows:

$$\text{Percent of Oil (Dry Basis)} = \frac{\text{Percent of Oil (Wet Basis)}}{100 - \text{Percent Moisture}} \times 100$$

### Limpness

Many attempts have been made to measure objectively the "limpness" of french fries. Limpness (both sensory and instrumental) is related to the specific gravity of the fry. Sensory evaluation of the "limpness" of french fries is not precise due to the subjectivity of the test and high variability between fries. A decrease in the variability may be accomplished by evaluating this attribute almost immediately after finish frying and draining. The Nylund limpness sag instrument is relatively simple to construct and use, and is therefore suggested as a means of objectively quantifying french fry limpness. A plastic model as shown in Fig. 21 is available from Shirley Munson, University of Minnesota, 1970 Falwell Avenue, St. Paul Minn. 55108, for a modest fee.

#### *Nylund Limpness Sag Instrument — Wooden Model*

##### Equipment:

1. Two blocks of wood or plastic approximately 5.5-6 inches x 2.5-3 inches x 3/4 inch
2. Protractor
3. Six 1/8-inch aluminum wire stock nails
4. Two smaller nails for nailing protractor to vertical block
5. Two screws for joining blocks of wood

##### Procedure:

1. Place one block horizontally and place the other block vertically at one end of horizontal block. Position screws approximately 3/4 to 1 inch from the sides and 3/8 inch up from bottom of vertical board and drive in to join boards.
2. Nail protractor to vertical board as shown in diagram.
3. Mark vertical board at the center of protractor and continue mark along back side of board.
4. Position nails along mark so the space between nails measures 9/32 inch. Drive in nails.
5. Round off pointed nails evenly.
6. From the front but behind the four nails, drive in two aluminum nails for a back rest. Clip off heads and round off.

#### *Munson and Nylund Limpness Method*

##### Equipment and Materials:

1. Nylund Limpness Sag Instrument
2. French fry sample (24 strips)

##### Procedure:

1. Measure length of fry.
2. Butt end of fry against two of the most closely spaced nails.
3. Read limpness from the top of the fry from the 90° mark. If the fry curves up, record sag as negative.
4. Repeat for all four sides.
5. Follow procedure for at least six fries.
6. Repeat test at 5-7 minute interval, 10-12 minute interval, and 20-22 minute interval.

Record data for length and average deflection for each fry. A deflection of more than 5° is an indicator of a limp strip.

Average Deflection =

$$\frac{\text{Sum of Degree Deflection for Four Sides}}{4}$$

The USDA has established quality grade standards for frozen french fried potatoes based on color, uniformity of size and symmetry, defects, and texture. Flavor is considered a factor of quality, but it is not scored; it is either acceptable or unacceptable. The grading system for frozen french fried potatoes is summarized in Table 11.

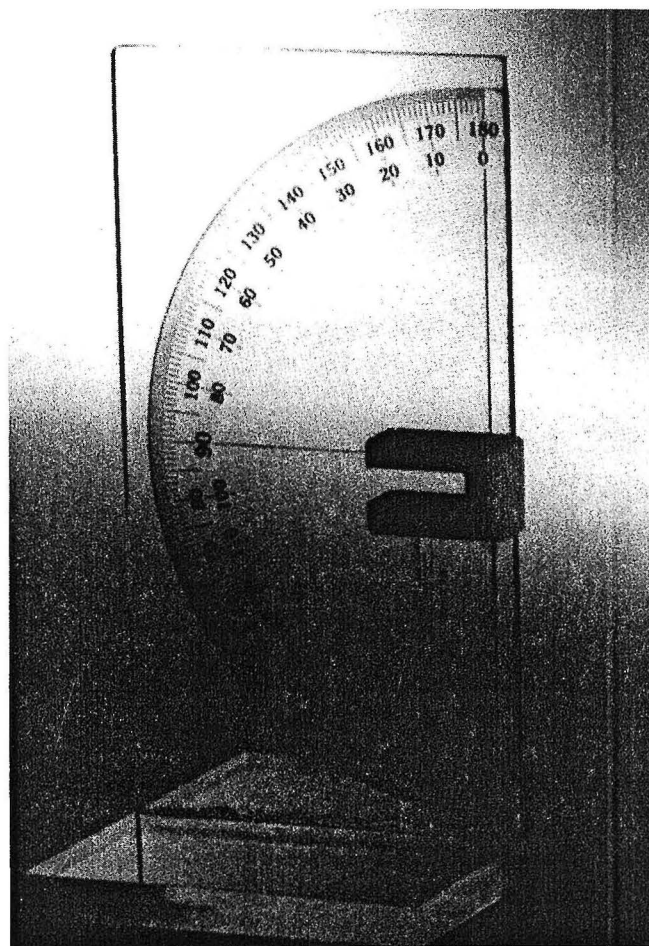


FIG. 21.—Nylund limpness sag instrument.

**TABLE 11.—Grade Scores by Factors for Quality of Frozen French Fries.**

Factors of Quality	Grade A Maximum Score	Grade A	Grade B	Substandard
Color	30	27-30	24-26	0-23
Uniformity Size and Symmetry	20	18-20	16-17	0-15
Defects	20	18-20	16-17	0-15
Texture	30	27-30	24-26	0-23
Minimum Score	100	90	80	—

Limits — lowest score for any factor determines grade classification.

The USDA recommends a sample size of at least 1 lb.

### Color

Color is an extremely important quality factor as evidenced by its maximum point value of 30 (see Table 11). This attribute should be evaluated before complete thawing has occurred, but after the surface frost has evaporated. Color standards are available by writing:

Processed Products Branch  
Fruit and Vegetable Quality Division  
Agricultural Marketing Service  
U.S. Department of Agriculture  
Washington, D.C. 20250

Color designations and their corresponding USDA color number are given in Table 12.

Color evaluation includes fry color evaluation after heating the product in oil at 365° F for 90 seconds and draining for 15 seconds.

**TABLE 12.—Fry Color Designation and Corresponding USDA Number.**

Fry Color Designation	Fry Color of the Units
Extra Light	Lighter than USDA No. 1
Light	Similar to USDA No. 1 color
Medium Light	Mostly similar to USDA No. 2, predominantly lighter than No. 3
Medium	Mostly similar to No. 3, may include units of No. 2 fry color
Dark	Predominantly darker than USDA No. 3, may include No. 4

**TABLE 13.—Color Scores as Indicated by Color Designations and Fry Color.**

Color Designation	Fry Color	Score
Extra Light, Light	USDA, No. 1, 2, 3, some 4	27-30
Medium Light or Medium	No. 1, 2, 3, 4 variation	24-26
Extra Light, Medium Light, or Dark	in fry color does not affect appearance	

### Uniformity of Size and Shape

The evaluation of size and symmetry should include a length designation and an indication of the uniformity of size and symmetry. Previously the shorts loss was determined for the processor, which would be a consideration in this category if the processor did not screen for shorts and slivers. Length designations for strip, straight cut style potatoes are given in Table 14.

U. S. Grade A frozen french fried potatoes are defined as “practically uniform in size and symmetry” and U. S. Grade B are “reasonably uniform in size and symmetry”. To warrant a score of 18-20, a product, regardless of size, must not contain more than 15% small pieces, slivers, and/or irregular pieces (*i.e.*, “pieces less than 1 inch in length”), weigh less than one-third the weight of an average unit of the same length, or “not have the general conformation of strips”. A second criterion is that “any chips (pieces of potato that are less than 1/2 inch in their greatest dimension) present no more than slightly detract from appearance of the product”. U. S. Grade B is given a score of 16-17 and requires that “chips present may not seriously detract from appearance; and not more than 30%, by count, may consist of small pieces, slivers, and/or irregular pieces.”

### Defects

Many of the defects in the product such as necrosis, discolored eyes, and callous areas are detected in the evaluation of the raw material. Some internal discolorations or darkening, however, will not become evident

**TABLE 14.—Length Designations for “Strip Style”.**

Length Designation	Criteria
Extra long	80% or more are 2 inches or longer; 30% or more are 3 inches or longer
Long	70% or more are 2 inches or longer; 15% or more are 3 inches or longer
Medium	50% or more are 2 inches or longer
Short	Less than 50% are 2 inches in length or longer



**TABLE 15.—Grade Classifications and Points Scored for Defects in Frozen French-Fried Potatoes.**

Grade Classification	Points Scored	Types of Defects	Maximum Defects in a 1 lb Sample
A	18-20	Minor and Major	5—Minor 1—Major
B	16-17	Major and Minor	9—Minor 2—Major

until after frying. Also, collapsed centers may be detected at this time.

Defects in french fries are defined as “imperfections in the product, such as necrosis, crushed (collapsed) units, discolored eyes, callous areas and discolorations which affect the appearance or edibility”. Defects which are of “little consequence” are termed “insignificant imperfections”. The definition of an insignificant imperfection depends on the intensity of color of the imperfection. If the discoloration (internal or surface) is very light in color, it is considered insignificant regardless of the size. A surface or internal discoloration which is light brown is designated insignificant as long as it is “equal to or smaller than the volume of a sphere 3/16 of an inch in diameter”. Dark brown discolorations (internal and surface) are termed “insignificant” if the defect is smaller than the area of a circle or volume of a sphere of 1/8 inch diameter.

Scoring for defects is accomplished by counting the number of major and minor defects in a 1 lb sample. Minor defects are those “imperfections” which detract, but not seriously so, from appearance or edibility. A more precise definition of these imperfections is:

1. Light brown surface or internal discolorations equal to or larger than the area of a circle or sphere, of 3/16 inch diameter but smaller than the area of a circle, or the volume of a sphere of 5/16 inch diameter; and
2. Dark brown surface or internal discolorations equal to or larger than the area of a circle or the volume of a sphere, of 1/8 inch diameter but smaller than the area of a circle, or the volume of a sphere of 1/4 inch diameter.

The term major defect is assigned to those “imperfections that seriously detract from appearance or edibility”. Imperfections considered “major” are “any dark brown surface or internal discolorations equal to or larger than the area of a circle, or the volume of a sphere of 1/4 inch diameter; and any condition of the potato which is offensive because of color, odor, character, or for any other reason.”

The points given for defects are summarized in Table 15.

### Texture

Texture may be evaluated by the USDA grade standards but should also be evaluated by a trained sensory panel. The USDA recommends that texture be evalu-

ated within 3 minutes after the finish fry and while it is still slightly hot (well above room temperature).

A score of 27-30 should be assigned for products which possess “a good texture, meaning that the external surfaces of the units are moderately crisp, show no noticeable separation from the inner portion, and are not excessively oily; the interior portions are well-cooked, tender, and practically free from sogginess.”

A score of 24-26 may be given for products which possess “a reasonably good texture, meaning that the external surfaces of the units may be slightly hard or slightly tough, showing no more than a moderate separation from the interior portion, and are not excessively oily; the interior portions are well-cooked, reasonably tender, and reasonably free from sogginess.”

### Sensory Evaluation

Sensory evaluation of the product for flavor and texture may be accomplished using the method described on page 51. The product should be finish fried for 90 seconds at 185° C (365° F) and served to each panelist within 3 minutes of preparation. Attributes to be evaluated by the panel are flavor, mealiness, limpness, and crust texture. Proper instructions on limpness and mealiness should be provided to the panelists to assure that each attribute is clearly defined. Limpness, as noted earlier, is the degree to which a fry bends when held horizontally at one end. Mealiness is related to the solids content of the potato and refers to the flow characteristics or viscosity of the cooked tissue.

### STORAGE EVALUATION

Raw potato storage is necessary to provide processors with the materials needed to meet an ever-increasing demand. Storage periods will vary from 1 week to 10 months depending on the location and the season. Good storage practices are to avoid low [10° C (50° F)] and high temperatures [15° C (60° F)] and to maintain proper ventilation, avoiding a decrease in oxygen but keeping the humidity above 85%.

Shrinkage during storage results from potato respiration in which water and carbon dioxide are lost. Some weight loss is also due to transpiration and rot and sprouting. Respiration and transpiration rates are affected by the storage temperature, relative humidity, oxygen level, cultivar, and maturity of the potatoes. Increases in temperature will increase these rates as will increased oxygen levels. Respiratory activity is also higher in immature and wounded tubers.

Evaporation during storage can effectively increase the specific gravity of potatoes. The increase in specific gravity, however, may result in increased sloughing during cooking. Therefore, reducing the moisture loss is desirable to maintain the original texture and degree of sloughing for cooked potatoes and to minimize weight loss, softening, and onset of blackspot.

The sugar content of the tuber is often the most seriously altered attribute of the tuber during storage. Increases in reducing sugar content result in browning, particularly for potato chips, but also for french fries and other potato products. Amylolytic enzymes convert starch to sugars in low temperature storage or other stressful conditions. Relieving the stresses (*i.e.*, increasing the temperature) may reverse the conversion, increasing the starch content. The amount of sugars formed during low temperature storage depends greatly upon the cultivar in question. Cultivars will also determine the capability of reversing the process and the time of onset for irreversible senescent sweetening. For these reasons, storage evaluation must include many temperatures, times, and reconditioning periods to determine the optimum and range of acceptable conditions for each cultivar.

### Storage Conditions

For a complete analysis of each cultivar's performance during storage, 15-20 lb of bagged samples are suggested from each replicate. An initial weight of each sample is required for determination of storage losses. A set of three bags should be stored at each of the following storage temperatures: 5° C (40° F), 7° C (45° F), 10° C (50° F), and 13° C (55° F). The storage facility must have proper ventilation and must have climate control to maintain a relative humidity of 85% or higher. The recommended storage periods for sampling are 1 month, 3 months, and 9 months. The storage loss is determined by weighing the bag and calculating as follows:

$$\text{Percent Storage Loss} = \frac{\text{Weight Loss}}{\text{Initial Weight}} \times 100$$

Reconditioning involves holding the potatoes at 21° C (70° F) for 1, 10, and 20 days. After each reconditioning period, a 5-lb sample is removed for processing and re-evaluated for specific gravity and glucose and sucrose contents. Evaluating the stored tubers for chipping will give the best indication of the effect of the storage on tuber quality, since browning may be more pronounced. Procedures for the determination of spe-

cific gravity, glucose and sucrose content, and chipping tests were given on pages 3-19. The cultivars should be evaluated over each temperature, storage period, and reconditioning period for recommendation of the cultivar under varying conditions.

### LITERATURE CITED

1. Anonymous. 1983. Agtron Model E-5F Service Manual 964-36. Magnuson Corp., Reno, Nev.
2. Ewing, E. E., W. A. Gould, R. B. O'Keefe, J. D. Harrington, and S. T. Munson. 1973. Compilation of Quality Evaluation Methods Used for Potato Chips and for Cooked Potatoes. NCM-45 Committee (Unpublished).
3. Gould, W. A. 1983. Food Quality Assurance. 2nd Ed., AVI Publishing Company, Inc., Westport, Conn.
4. Gould, W. A. 1980. Quality Control Procedures for the Manufacture of Potato Chips and Snack Foods. Potato Chip/Snack Foods Association.
5. Gould, W. A. 1979. Evaluation of Potato Cultivars Before and After Storage Regimes for Chipping. Am Pot. J., Vol. 56, pp. 133-143.
6. Gould, W. A. 1976. Quality Assurance Manual for the Manufacture of Potato Chips and Snack Foods. Potato Chip/Snack Food Association.
7. Hess, J. and D. P. Mitchell, ed. 1984. Snack Food: 16th Annual State of the Snack Food Industries Report. Snack Food, 73(6):M9.
8. Lulai, E. C. and P. H. Orr. 1979. Influence of Potato Specific Gravity on Yield and Oil Content of Chips. Am. Pot. J., Vol. 56, pp. 379-390.
9. Nylund, R. E. and S. T. Munson. 1979. A Preliminary Report on Factors Affecting Limpness of French Fried Potatoes. NC-150 Committee Report.
10. Smith, O. 1977. Potatoes: Production, Storing, Processing. 2nd Ed., AVI Publishing Company, Inc., Westport, Conn.
11. Talburt, W. F. and O. Smith. 1975. Potato Processing. 3rd Ed., AVI Publishing Company, Inc., Westport, Conn.
12. USDA. 1982. Potatoes and Sweet Potatoes, 1980-1981. Production, Disposition, Value Stocks and Utilization. Crop Reporting Board, Statistical Reporting Service, USDA, Washington, D. C., Pot., 6(82):12.

### Potato Cultivar Evaluation

Name \_\_\_\_\_ Harvest Date \_\_\_\_\_ Process Date \_\_\_\_\_

Maturity-Feathering \_\_\_\_\_ Percent Skin Set \_\_\_\_\_ Sucrose Value \_\_\_\_\_

Pulp Temperature \_\_\_\_\_ ° C Percent Disease Free \_\_\_\_\_ Percent Bruise Free \_\_\_\_\_

Tuber Shape Length (cm) \_\_\_\_\_ Diameter (cm) \_\_\_\_\_

Tuber Shape — Elliptical \_\_\_\_\_ Round \_\_\_\_\_ Cylindrical \_\_\_\_\_ Oblong \_\_\_\_\_

Tuber Size — Percent Small \_\_\_\_\_ Percent Medium \_\_\_\_\_ Percent Large \_\_\_\_\_ Percent Extra Large \_\_\_\_\_

Tuber — Smooth \_\_\_\_\_ Russet \_\_\_\_\_ Rough \_\_\_\_\_

Tuber — White \_\_\_\_\_ Brown \_\_\_\_\_ Red \_\_\_\_\_

Tuber Peel — 1/16 inch \_\_\_\_\_ 1/8 inch \_\_\_\_\_ More than 1/8 inch \_\_\_\_\_

Tuber Eyes — Shallow \_\_\_\_\_ Medium \_\_\_\_\_ Deep \_\_\_\_\_

Absence of Defects — Sprouts \_\_\_\_\_ Greening \_\_\_\_\_ Cleanliness \_\_\_\_\_

Specific Gravity \_\_\_\_\_ No. of Tubers/8 lb \_\_\_\_\_

Percent Peel Loss \_\_\_\_\_ Percent Trim Loss \_\_\_\_\_

Flesh Color — White \_\_\_\_\_ Creamy \_\_\_\_\_ Yellow \_\_\_\_\_

Vascular Ring Appearance — Normal \_\_\_\_\_ Translucent \_\_\_\_\_ Discolored \_\_\_\_\_

### Potato Chip Quality Evaluation

Chip Color (PC/SFA 1-5) \_\_\_\_\_ Agtron Model No. \_\_\_\_\_ Agtron Value \_\_\_\_\_ Color Score \_\_\_\_\_

Minor Defects in Percent \_\_\_\_\_ Major Defects in Percent \_\_\_\_\_ Blisters Percent \_\_\_\_\_

Hash Percent \_\_\_\_\_ Defect Score (0-20) \_\_\_\_\_ Bulking ml/g \_\_\_\_\_

Texture Score (0-20) \_\_\_\_\_ Flavor Score (0-30) \_\_\_\_\_ Total Score \_\_\_\_\_

### French Fry Quality Evaluation

Texture Score (0-30) \_\_\_\_\_ Color Score (0-30) \_\_\_\_\_ Defect Score (0-20) \_\_\_\_\_

FF Size Classification — Extra Long \_\_\_\_\_ Long \_\_\_\_\_ Medium \_\_\_\_\_ Short \_\_\_\_\_

Uniformity of Size and Symmetry Score (0-20) \_\_\_\_\_

Limpness Deflection \_\_\_\_\_ Total Score \_\_\_\_\_